HYBRID HERITAGE: AN INVISTIGATION INTO THE VIABILITY OF 3D-PRINTED MASHRABIYA WINDOW SCREENS FOR BAHRAINI DWELLINGS

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ABSTRACT

Current debates on design and manufacturing support the claim that the 'Third Industrial Revolution' has already started due to Additive Manufacturing (AM) and 3D Printing. The process of solidifying liquid or powder using a binding agent or a melting laser can save time and transportation costs associated with importing primary material if locally sourced material is available. This research investigates a framework approach, titled SAFE, for discussing the functionality, economic viability, production feasibility, and aesthetic and cultural value lent by 3D printing on an architectural scale through a construction known as a Mashrabiya. This traditional window screen has distinguished aesthetic, cultural yet functional constraints, and there is a manufacturing gap in the market that makes it a viable product option to be 3D printed. The practical element and design process related to reviving this screen are examined, from complex geometry development to cost and fabrication estimations.

3D printing technologies potentially offer solutions to solve issues in construction and assembly times, reduce labour costs, and address the loss of hand craft making skills in a variety of cultures, typically Middle Eastern ones; this was a factor in the abandonment of old Mashrabiya in houses typified with Bahrain as a case. Presently, there is a growing wealth of literature that highlights not only the strength of Mashrabiya as a design concept but also as a possible 3D printed product. Interviews with a total of 42 local Bahraini manufacturers, academics and architects as well as 4 case studies and 2 surveys and 11 focus groups are hybrid mixed methods used to define a new 3D printed Mashrabiya (3DPM) prototype. The future of the 3D Mashrabiya prototype is further supported by economic forecasts, market research, and interviews with global manufacturers and 3D printing designers' insights into the subject in an accretive design process.

The research contributes to an understanding of the implications of technologies that enable mass customisation in the field of 3D-printed architecture in general and in the Bahraini market in particular. The process for developing a prototype screen and in determining its current economic value will prove significant in predicting the future benefits and obstacles of 3D-printed large scale architectural products in the coming five years as advised by industry experts. The main outcomes relate to establishing boundaries determining the validity of using 3D printing and a SAFE framework to produce a parametric Mashrabiya and other similar heritage architectural archetypes. This can be used to enhance the globalism of the design of Middle Eastern dwellings and to revive social identity and cultural traditions through innovative and reasonable yet superior design solutions using a hybrid architectural design language.

DEDICATION

To Islam, a religion, a policy and a guide of every day and everyone…

To my beloved children Abdulla and Ali, every minute I spent away was for a better good, for you both and for the generation after…

To my husband and family, I could not have done this without you all, you were the blessings and gifts I can never thank God enough for…

To all Muslim women out there, you are precious diamonds and rare, veiled for the eyes of the ones who really care…

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STATEMENT OF INTENT

I cannot claim that I can change the world, but I can simply play my part.
As a Muslim veiled woman,
as a Bahraini conservative housewife who appreciates her privacy,
as an interior designer who cares about users' culture, background, taste and daily life routine,
as an architect understanding the social context, aesthetics and functional yet affordable design solutions,
as a product designer of emotional, feminine yet revolutionised traditional screens,
as a researcher who cherishes variable knowledge, understands the supremacy of industrial and technological constraints yet challenges them.
A new Mashrabiya is hitherto a treasure that mediates between architecture, the interior, and product and research domains and elevates to the morals and beliefs of not just human needs but human nature itself.

Nehal Ali Almerbati

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ABBREVIATIONS AND DEFINITION OF TERMS

Abbreviation	Explanation
2D	Two-dimensional
3D	Three-dimensional
3DP	Three-dimensional Printing
3DPM	3D-printed Mashrabiya
ABC	Activity-based Costing
ABS	Acrylonitrile Butadiene Styrene
Agassi	A Bahraini exposed closed balcony of wooden louvre
AM	Additive Manufacturing
ASP	Average Selling Price
BDB	Bahrain Development Bank
BIM	Building Information Modeling
CAD	Computer-aided Design
CAGR	Compound Annual Growth Rate
CAM	Computer-aided Manufacturing
CIM	Computer-integrated Manufacturing
CM	Cloud Manufacturing
CNC	Computer Numerically Controlled (machining)
DFAM	Design For Additive Manufacturing
DFM	Design For Manufacturability
DMD	Direct Metal Deposition
DMLS	Direct Metal Laser Sintering (EOS GmbH trademark)
DMU	De Montfort University
EDB	Bahrain Economic Development Board
FDM	Fused Deposition Modeling
GCCC	Gulf Cooperation Council Countries (Bahrain, Oman, Kuwait, Qatar, Saudi Arabia, Iraq)
GRC	Glass fibre Reinforced Concrete
GRG	Glass Reinforced Gypsum
Harim	Women in Arabic
Haramlak	Women's quarter in a house or palace
Hurma	Women or private space essence of mosque or the house that cannot be violated in Islam
IP	Intellectual Property
Karkari	The Bahraini local name for a simple Mashrabiya design of a timber louvred balcony projection

ME	Middle East
MENA	Middle East and North Africa
Roshan	A common Mashrabiya-like window in Saudi Arabia, one of the GCC countries, plural: rawashen in Arabic
RP	Rapid Prototyping
Salamlak	Men's quarter in a house or palace
SLS	Selective Laser Sintering
STL	File format for 3D printing
Tamkeen	A Bahraini organisation dedicated to enable the private sector to be a key driver in Bahrain's economic development
VOA	Value Opportunity Analysis

DEFINITION OF TERMS

Mashrabiya	Window lattice screen generally made out of wood but recently moulded out of gypsum reinforced concrete GRC. It functions to provide visual privacy for women of the house in Islamic societies; it also has a function of passively cooling the interior space behind it.
3D printing	The process of solidifying liquid or powder using a binding agent or a melting laser. The process involves transferring a CAD file into an STL file that can be printed using 3D printers.
Holistic approach	Relates to the idea that things should be investigated as a whole and not just as a sum of their parts, while the Oxford English Dictionary defines it as the belief that the parts of something are explicable only by reference to the whole.
Sustainable heritage	The main definitions of sustainability and heritage are collectively used to describe how can heritage elements and material reflect changes in the social, political, economic and functional change in globalised economies.
SAFE	A collection of holistic values, initiated by Kumar (2008), to combine Social, Altruistic, Functional and Emotional values. These values are developed by the author to relate to architecture products. The new SAFE values refer to Social, Aesthetic, Functional and Economic values.
Parametric design	A design process that is based on algorithmic thinking, which enables the expression of parameters and rules. Together these codes define, clarify and encode the relationship between form design intent and design response. Grasshopper is a plugin that generates such designs.
Architectonic	The scientific study of Architecture and its building form.
Digital craftsman	A person who is very skilled in using technology and computer modelling software to create digital objects to be crafted or built.

CHAPTER 1

"Research is to see what everybody else has seen, and to think what nobody else has thought"

Albert Szent-Gyorgyi

CHAPTER 1: INTRODUCTION AND RESEARCH CONTEXT

1.1 INTRODUCTION TO CHAPTER

The Mashrabiya is a remarkable yet lost window screen seen in heritage buildings in the GCC but rarely exist nowadays. This chapter provides an insight into the research content about the loss of Mashrabiya screens and the heritage identity problem associated with it and reflected in today's architecture and industry. It also frames the potential way in which this problem can be solved. Section 1.2 starts by setting the scene and providing an understanding the background of this research. Section 1.3 then introduces the context of Bahrain as the focus of the study. Bahrain is similar to other Arabian Gulf Cooperation Council Countries (GCC) as all share almost the same culture, and it has been influenced by modern trends as well. Section 1.4 introduces the research problem found in Bahrain. Section 1.5 outlines the research aim and objectives in relation to the identified problem. Furthermore, Section 1.6 pinpoints the limitations faced and frames the research in its current scope, while section 1.7 represent an introduction to the research paradigm and its mixed method approach. Finally, in Section 1.8 a summary of the adopted methodology is put forward, and a visual representation of the research chapter sequence in this thesis is presented in Section 1.9.

1.2 RESEARCH BACKGROUND

Looking at the current architectural scene in the world in general and in the Middle East in particular, it is evident that it has been a canvas for several creative forms that are not necessarily functional. The design rules in this digital era have changed a lot of the sustainable vernacular buildings, their heritage traditions and architectural concepts of 'form follows function' once stated by Louis Sullivan (1896) to 'form follows trends' as suggested by Abdelsalam and Rihan (2013) or 'form follows fantasy' as proposed by Phillippe Starck (2014). Still, creating sustainable architecture and interiors that are environmentally responsive ones as well is the targets of many architects and designers around the globe. Countries in the Middle East, like other countries, have set sustainable visions for their market, that consider sustaining culture, environment and economics.

Nevertheless, the importance of technological development and how it revolutionises architecture can never be ignored. This was especially relevant after the first and second industrial revolutions that happened in 1840–1870 and then in 1870–1914. The development of Portland cement in 1824 is just one example of how an advanced material replaced traditional iron and steel structure buildings. Thus, this led to the creative leap of the invention of reinforced concrete in the 19th century; as Net Industries (2009) claim, this resulted in changes in the way buildings look and in their structure. A distinguishable turning point was the development of a new quality of glass material. The size and cost of this material has substantially changed architecture. Masonry wall-framed structures were replaced with large glazed openings, especially in the facades of commercial buildings, regardless of the heat burden they require.

While the second industrial revolution focused on mass production, the claim currently made by the Economist (2012) is that digital manufacturing will start a new mass customisation era, yet not the third industrial revolution argued by Reeves (2015). This claim is justified as follows:

> *"The old way of making things involved taking lots of parts and screwing or welding them together. Now a product can be designed on a computer and "printed" on a 3D printer, which creates a solid object by building up successive layers of material. The digital design can be tweaked with a few mouse clicks. The 3D printer can run unattended, and can make many things which are too complex for a traditional factory to handle. In time, these amazing machines may be able to make almost anything, anywhere—from your garage to an African village" (The Economist, 2012).*

Making anything anywhere may not be the reality of this manufacturing era. Hopkinson (2006) focused on this era of Additive Manufacturing (AM), Rapid Prototyping (RP) and 3D Printing (3DP) and their role in the third industrial revolution in the digital age. The advantages of AM and 3DP can include increasing the opportunity to develop new design approaches, and revolutionising the design and manufacturing of products; in addition, they allow greater design freedom, reduce development time, accelerate marketing time and make the manufacture of what was impossible possible. However, Ford and Dean (2013) clarify that the media offer a clouded judgement of the possibilities and true role of AM in todays' manufacturing; views are not so supportive from an academic and practice-based point of view.

The advanced technology and uses of AM and 3DP for architectural production is still in its infancy and is not well established in the literature. Experimental projects, from hypothetical concepts to aesthetically appealing geometric models and 3D-printed houses, have been in the headlines of the architecture news in the last three to five years. But there is a strong need to justify the form, materials used, scale and associated AM and 3DP technology and the economic implications this adds to projects in order to advance the field of 3DP for architecture and to push forward its development cycle.

Many obstacles can be noted that slow the development cycle of 3DP for architecture. First, there is a lack of research bodies that are entirely dedicated to the advancement of AM and 3DP. However, the research group team at Loughborough University are a good example of a collaboration between industry and academia, especially after their recent agreement with Foster and Partners and Buro Happold. The research group has built a significant AM machine with a build volume of 2m x 2.5m x 5m to manufacture the world's first reinforced concrete component, as stated on the Loughborough University website (2015). Other obstacles include the cost and characteristics of materials and the scale of AM and 3DP machines, as well as the digital software they need.

Intensive investigations into the opportunities and obstacles facing architectural production using 3DP is therefore a valid concern for 21st-century industries and academia to examine. However, specific contexts must be taken into consideration to combine appropriate input variables and forms with specific outputs that serve the industry and its design capabilities. The technology cannot be separated from the market it is planned to overtake, the region it serves and the climate conditions it should operate in.

The topic of this PhD research aims to fill gaps in the existing literature knowledge and manufacturing potentials as discussed in Chapter 2 and 3. It also aims to reframe a holistic approach for future anticipation of the social, aesthetic, functional and economic variables of additively manufactured and architectural 3D-printed possible products in Bahrain as a case study. Thus, the results can then be generalised to similar countries which share Bahrain's characteristics such as the surrounding GCC countries and some other Middle East countries.

1.3 WHY BAHRAIN?

The small island of Bahrain has been chosen as the context for this study. Historical evidence and current evidence marks Bahrain as having been at the crossroads of commercial importance for over 4,000 years and it has continued to be so after being the first Gulf state to discover oil in 1932 (Bahrain.com, 2015). Bahrain's economy, population, climate and architecture is representative of the Gulf region. It shares similar Islamic religious beliefs and traditions to its neighbouring GCC countries. This is due to the importance of culture, and the social and emotional attachment Bahrainis have to their architectural facades. Facades are a distinctive feature that relate to the selection of the studied architectural product, Mashrabiya or window screen, in this research.

The revolution in Bahrain's architectural trends and forms from the pearl diving period to after oil discovery in the last 100 years is a remarkable period of growth that cannot be ignored. Instead, architectural language, approaches and trends in relation to craft and current manufacturing technology should be studied, analysed and forecasted for years to come. The advantages of selecting Bahrain as study context depended on the researcher own background and knowledge of the context of Bahrain. Moreover its relative small size makes it beneficial for extracting and understanding the research constraints, and it is also possible to use Bahrain as a case to reflect on other GCC countries. In 2008, Bahrain, as well as other GCC countries, launched its 2030 sustainable vision (EDB, 2014). Since then, industries and cultural awareness and development projects started accelerating, but clear valid approaches have not yet proven successful on a local scale. This research is therefore needed to bridge the gap between new Bahraini architectural trends, its culture and its modes of production.

1.4 PROBLEM STATEMENT

The purpose of this research is to examine the viability of using 3D printing to produce architectural window screens known as Mashrabiya for Bahraini houses in the Middle East. A hybrid mixed methods approach is used to validate the themes and patterns on a social, aesthetic and functional level, as well as the economic constraints that could influence the future production of 3DP Mashrabiya screens. The environmental capital of Mashrabiya as a window shading device has previously been proven to be viable by other scholars (such as Abdelgelil, 2006 and Samuels, 2011) while proposing new Mashrabiya screens. Therefore, these studies will be considered in the present research when examining the functional value of the new screen that is being investigated. Hence, the validity of the environmental capital will rely on secondary sources, and their guidelines will be followed in designing environmentally responsive Mashrabiyas.

This research reflects on current architectural practices as well as scholarly author's discussions in the field of architecture who have attempted to revive traditional screens and make good use of the advancement of manufacturing techniques to create more sustainable facades, as detailed in Chapter 2. Masdar City, the world's first zero energy community as the Guardian (2011) highlight it, is one of the places that has used new and enhanced GRC technique in producing Mashrabiya screens in its development to reflect both social and functional issues in a hybrid yet aesthetic way. A coherent understanding of the economic and technological context is, however, missing in these academic scholarly articles and practices as discussed in Chapter 3. Moreover, new aesthetically appealing Mashrabiya possibilities have mostly been restricted to serving window's functionality role. Instead, a need for a new balance between function and aesthetics exists in today's modern architecture and interiors.

The importance of the researched problem is interconnected with the importance of understanding architecture down to its smallest details. This includes the context of the building to be designed, the occupant's needs, social and cultural beliefs, as well as functional needs and aesthetic aspirations. More importantly, architectural products and design elements should be used as tools to advance the wellbeing of the building's occupants, regardless of their economic status.

Moreover, the economic growth following the discovery of oil accelerated development, and globalisation generated new morphologies in the Gulf region. This is noted by Ben Hamouche (2004) as a shift from 'endogenous' to 'exogenous' types of urban growth. In architecture and design, a similar shift has also been noticed in the move from 'traditional' to 'neo-traditional' to 'contemporary-oriented' trends, as discussed by Abdelsalam and Rihan (2013). As Dayaratne

(2008) argues, the intimate relationship within Gulf cities between the built environment and Islamic cultural values has also been fractured.

The implications resulting from such rapid urban development have affected architectural identity, heritage conservation, energy conservation and lighting quality issues within modern houses. Values of privacy, for example, have been violated in certain cases, as researched by Sidawi (2012) and Aljawder (2014). This has generated alerts for governments and building authorities to take action to bring about more cautious development. Through examining the literature of the last decade, architects' and scholars' recommendations and calls for change within the built environment can be outlined in chronological order by reference to the following voices:

1. Albaher (1985) as cited by Alenazy (2007) relates the loss of identity to both designers and Gulf citizens, Kuwaitis, in his example. The flow of Arabs and people of non-Arab nationalities to work and design within Gulf cities has led to the possibility of spreading confused thoughts over architecture as most of these people do not understand the real values. It is therefore the owner's responsibility to ensure that a social and functional requirements list is fulfilled by architects or Westerners who are not well acquainted with these values.
2. Wally (1993) equates the role of the Muslim architect to that of a God worshipper in terms of his role in design according to Islamic rules, values and principles. Architects should take care while designing and not favour modernity aesthetics and ignore real values and social understanding. His role as a creative and design implementer should be to respect traditions, religion and to use materials of a reasonable cost.
3. Dayaratne and Karajica (2007) identify a current dilemma with globalisation and architecture in the modern world in general and in the Middle East in particular that needs investigation and reflection.
4. Almurahhem (2008) uses Jean Nouvel's Arab World Museum concept as an example to show that modern technology and traditional architecture can successfully combine to bring about benefits for occupants without the need to disregard Arab cultural heritage.
5. Ghiasvand (2008) and Moradi (2008) argue that there is a need to appreciate, understand and evaluate the architectural quality of traditional buildings. They envisage a need to develop a sense of dimension, climate, topography, materials, physical natural and human-made environment as well as proportions to go beyond utilitarian needs. They highlight the fact that rapid growth in Gulf countries means that it is time for in-depth architectural research studies or a comprehensive new interpretation of the finest values of Islamic architecture and its traditions. A real test of Muslim architects' ingenuity, they suggest, is to be able to merge the spirit and beauty of ancient architecture and current technological advances within a modern idiom.

6. Eldemery (2009) addresses decision makers by providing a set of guidelines to be used, which can be operationalised and applied in future local projects. His emphasis is on the importance of the change in living patterns and technological innovations. He also urges architects to think "glocally", a composite term for appreciating the local context in its global position. This is done using traditional consciousness and maturity of future vision.
7. Omar as cited in Sidawi (2012) rejects the "copy-paste" of applying old archetypes to new buildings.
8. Abdelsalam and Rihan (2013) encourage an understanding of the inherited values in traditional architecture and their reflection in modern architecture. He argues that architects should use these values and architectural elements to generate an appropriate regional identity.
9. Ajaj and Pugnaloni (2014) calls for a serious analysis of the rich architectural heritage context. Consideration should be given to the human, cultural and environmental values of this context. Conscious adaptation and implementation should be integrated within the context of contemporary conditions and technology.

The above concerns identified in the literature best describe the present dilemmas and problems in the Middle East in general and can be applied to Bahrain in particular. Although new visions for the sustainability of communities in the Middle East and GCC have been established and outlined, their implications are still questionable. The Bahrain economic vision 2030, for example, aspires to shift the oil-based economy to a productive and globally competitive economy (EDB, 2016). By diversifying away from oil and emphasising industry, logistics, financial services and tourism, Bahrain wishes to overcome its current key economic challenges, as noted in a Gulf news analysis (Ali, 2008). However, in reality this has not been implemented on a large scale; Bahrain still imports much of its market supplies and products. The Bahraini craft and manufacturing industry has also been trying to cope with globalisation trends and needs.

On the other hand, although sustainable development is the target of the Bahrain vison for 2030, it looks like the focus has been diverted to sustainable 'economic' development, as observed by Wai-Yin and Shu-Yun (2004) in similar developing countries. This is evident in the government race to build new infrastructures and iconic buildings to house global financial institutions where the local identity and values of Bahrain culture are arguably being lost. Sustainable development should include sustaining culture, because culture can be looked at as a sophisticated system as follows:

> "*…all the shared products of a given society: Its values, knowledge, norms and material goods…. It consists of the 'non-material' (knowledge, values, beliefs and social norms) and material (arts, crafts, clothing, dwellings, tools, etc.) aspects of a society.*" (Furze et al., 1996, cited in Wai-Yin and Shu-Yun, 2004, p.17)

Consequently, the current Bahraini culture is the product of its society over the years, most of which is controlled by its Islamic beliefs and environmental constrains and new income lifestyle. Bahrain's location and markets has established links with commerce and trade hubs like India throughout history. Today, its current market and manufacturing capabilities are a reflection of these past connections. A mixture of original crafts and foreign craftsmen skills with imported materials and goods are now influenced by regional design and architectural trends. The impact of manufacturing trends on craft and the building environment is a topic that is absent from the literature. Initiatives of the Bahrain Economic Development Board (EDB) strategies were only seen in their annual reports and newspaper articles. New manufacturing possibilities and new socio-economic architectural solutions are needed to balance the Bahraini development cycle and to sustain its heritage values for future generations.

Mashrabiya is one of Bahrain's architectural elements that can be considered as a production of a 'culture made material', as defined by Grier (1996) and discussed intensively by Almerbati et al. (2016). The traditional function of Mashrabiya was largely a result of its adherence to social and environmental roles. However, the old veiling product has almost vanished from today's architecture and housing designs. Nevertheless, new innovative forms of Mashrabiya have been developing and regenerating in current architectural and interior practices. International architectural facades, interior design projects as well as Oriental products have fused new concepts of the Mashrabiya to fit in with today's lifestyle.

The present research synthesises all data about Mashrabiya, summarising the current problems facing its manufacture in Bahrain, and tries to analyse how these can be solved using advanced technologies and new design language. Global manufacturing trends are examined and compared with market possibilities. Digital fabrication in particular will be intensely viewed in terms of 3DP to seek new ways of advancing and balancing architectural identity today. Moreover, international and local market economic analysis will be needed to forecast possibilities and review current processes.

However, Bahrain's development economy, faces several dilemmas. Elmasri (2010) highlights these dilemmas as being related to a lack of local expertise, the huge number of foreign experts and labourers, and a misunderstanding of the value and potentials of traditional architecture. The former can lead to the disappearance and deterioration of traditional settlements. Karolak (2010) gives an opposing optimistic view towards Bahrain's economy by suggesting that the modernisation and globalisation of Bahrain can provide a better economy. Her argument supports the notion that urbanisation stimulation, marketisation and industrialisation can highly benefit the economy and that the obstacles mentioned earlier by Elmasri (2010) can be consciously overcome.

The manufacturing market has also been affected by the shift in the built environment. Four famous crafts were noteworthy locally: the metalwork of window grilles, timber wood fretwork used in window screens and ceilings, door and shutter wood carving, fanlight stained glass and plaster carving (Yarwood, 1988). Bahrain's old craftsmanship in pottery and boat making could not survive modernisation, regardless of their influence on the architecture of Bahrain (Dayrante, 2008). Also, Ben Hamouche (2004) argues that the growth of the service sector is causing traditional crafts, artefacts and markets to collapse. From craft to construction, Alaali (2006) gives evidence of the change to a new construction industry that offers imported concrete and aggregate to replace traditional material resources like limestone. This can be an acceptable result; as Samuels (2011) suggests, the industrial revolution, followed by huge economic changes, made it financially impossible for traditional craft-based architecture to survive.

From architectural manufacturing aspects to design and prototyping solutions, CAD modelling knowledge is acquired by university graduates and designers in Bahrain. Yet digital fabrication is not well established. Ahmadi's (2014) investigation into the Bahraini new manufacturing market confirms the minor use of digital fabrication using CAD and CAM tools.

However, there is a gap in knowledge when it comes to the advanced application of digital fabrication in architecture, as it is still in its infancy. One supplier of 3D printers (KBproto shop) and a few jewellery designers are relying on digital craftsmen for the use of 3DP in their small-scale designs. However, architecture firms mostly rely on foreign craftsmen with CAD and 3DS Max rendering skills. Therefore, it can be argued that the quality of the digital craftsmen versus that of manual craftsmen is highly dependent on foreign workers' previously acquired skills and not the Bahraini market demand. Increasing knowledge, awareness and educational programmes and the Fab Labs studio in Bahrain, as suggested by Ahmadi (2014), can be a way to bridge the gap between the architecture and manufacturing markets in Bahrain; this is also the aim of the present research.

1.5 AIMS, OBJECTIVES AND RESEARCH RATIONALE

The aim of this research is to assess the validity of 3D manufacturing techniques in sustaining the use of Mashrabiya in 21st-century Bahraini houses.

The rationale behind selecting this research topic is based on factors associated with architectural conservation through future manufacturing awareness. Many researchers (Abdeldelil 2009; Samuels 2011) and architects, as previously explained, have delved into new technologies without taking into consideration aspects such as the social, aesthetic or economic context. This research fills a gap in the knowledge in testing a new technology known as 3DP to produce a large-scale Mashrabiya screen using a holistic approach to design and manufacturing. The research challenges current market manufacturing techniques and promotes the use of digital craftsmen as a means to empower the advancement of the heritage conservation of traditional architectural screens in a contemporary style. Further **justification** for undertaking this research are outlined below:

- The versatile link between architecture, interior and product design and technology.
- The importance of utilising technology for the advancement of architectural products.
- 'Form follows function' or 'form follows context'. Understanding the social and cultural as well as religious backgrounds and ideologies can strongly influence decision-making and the design stage of any product.
- Environmental constraints and means of technology might be the best generator of creative solutions.
- The importance of product growth cycles and economics in every new product proposal.
- Modernisation, design globalisation and increasing Mashrabiya manufacturing costs have stimulated more stylish and cost-effective shading device options.
- The call to revive traditional identity in houses, along with the fact that the new housing projects require more energy-efficient yet stylish and personal products, has revived the need to look for easily customisable and unique products that have never been designed before.

By examining the previous research rationale and problems found while conducting an initial literature review, refined research objectives were generated.

In addition, it focuses on the formation of a theoretical framework that can identify and anticipate the future of 3DP architectural features of this type.

Research objectives are:

1- To gather and critically evaluate the literature about Islamic architectural values and heritage conservation in relation to the form and usage of Mashrabiya in current architecture practices, especially in GCC countries like Bahrain.
2- To establish a coherent understanding of the current manufacturing market and its techniques, as well as its economic implications, and manufacturing complications in producing Mashrabiya in Bahrain.
3- To develop a theoretical framework of a set of values that can identify and anticipate the future of 3DP and heritage architecture and assess 3D-printed Mashrabiya as a case of a hybrid heritage solution.
4- To evaluate the perception of 3D-printed Mashrabiya and its associated values as an architectural-scale product in Bahraini houses.
5- To ascertain the usefulness of the theoretical framework as a tool for sustaining the use of Mashrabiya in modern architecture.

Initial research question

The main research question is as follows: What is the viability of using additive manufacturing to produce Mashrabiya window screens for 21st-century dwellings in Bahrain?

Sub-questions will include:

I. What is the need behind reviving the production of traditional Mashrabiya screens?
II. What are the current manufacturing processes to produce Mashrabiya?
III. How much does it cost to produce Mashrabiya locally?
IV. How much will it cost to 3D-print Mashrabiya screens?
V. What are the benefits and obstacles of each manufacturing technique?
VI. When will it be economically viable to produce 3DP Mashrabiya in Bahrain?

Refined research questions were considered after conducting the literature review:

1- Why is the use of Mashrabiya declining in Bahraini architecture?
2- Is there a need to revive the use of Mashrabiya in Bahraini architecture?
3- What are the current manufacturing processes that are used to produce Mashrabiya and what are the associated economic implications of such processes?
4- What are the potential benefits and obstacles in adopting 3DP techniques to produce Mashrabiya?
5- What are the values that would be used to determine the validity of 3DP in producing Mashrabiya?

1.6 SCOPE AND LIMITATIONS

This study focuses on the viability of 3D printing an architectural window screen for domestic houses and buildings in Bahrain as a reflection of other GCC countries in the Middle East. Bahrain has been chosen as the context for this research topic as it has a relatively small market yet has a powerful influence on the markets of other similar GCC countries. Bahrain also resembles an Islamic country that respects religious traditions and the culture of privacy and the veil, like many other Muslim countries in the Middle East. Furthermore, Bahrain was chosen as it has a unique blend of architectural patterns and projects that have translated into rich visual material and an adequate amount of literature that enables the research objectives to be fulfilled. Moreover, the researcher's familiarity with the language, culture, local manufacturing market, her academic connections and personal and practical wide networks made Bahrain an ideal developing country for obtaining new data in the field of 3D printing for architecture. The scope covers wide aspects, as seen in Figure 1-1.

However, the scale of the product of interest is a design challenge but is also a limitation for this research. This is because producing a prototype to be tested on a real scale costs more than De Montfort University can fund. The software and possible location for testing are accessible but generating the full scale size would require a specialised machine and additional transportation and fixing costs. Moreover, most of the economic forecasting gained from specialists and 3DP experts was based on 'magic' rather than 'actual data'. This is because of the rapid growth of 3DP in terms of daily new materials, and enhancements of machine size and speed that cannot be really estimated.

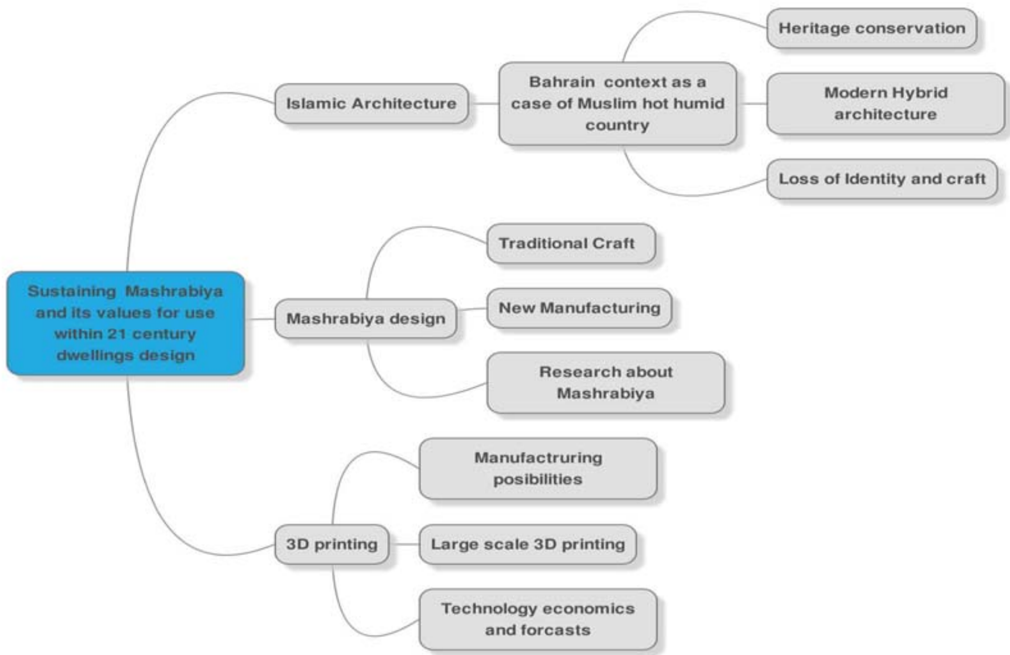


Figure 1-1: Research scope and mind map. Source: Author.

1.7 RESEARCH PARADIGM AND METHODOLOGY

According to Killam (2013), any research project is guided by a set of beliefs that are widely known as paradigms. The paradigm that best delineates the present research is the methodological paradigm described by Creswell (1994) and Killam (2013), which combines two categories: quantitative and qualitative paradigms. The reason for selecting this paradigm is that it is the most practical yet systematic way of addressing the researched topic that spans the area between architecture, manufacturing and current practices as well as involving economics and cost figures.

The research argument and methodology selection fall under the qualitative paradigm using an inductive approach. The informal and observed rationale was derived from the body of literature, involving decisions resulting from the evaluation of a few design categories during the research process. Unlike the quantitative paradigm, this research within the qualitative paradigm is contextually bounded to architecture and the Middle East, and therefore the research outcomes may not be generalised globally.

The theories and patterns developed are used merely to understand the market and for presenting accurate and reliable facts through verification, as recommended by Creswell (1994). The research structure uses a theoretical framework suggested by Maxwell (2005) that can serve two purposes. First, it will demonstrate how this research fits into what is already known from other subject-related research such as architecture, product design and 3DP. Second, it will show the gaps in the existing knowledge and the positive aspects that this research can contribute to the body of knowledge.

The methodology used is derived from understanding the research problem and the qualitative paradigm it fits into. A mixed methods approach from a quantitative Bahraini residents' survey is combined with qualitative methods used to explore the research area. The research is divided into three phases, with each phase interlinked with one other. The first phase discusses four case studies about buildings that have revived the use of Mashrabiya screens in local, regional and global contexts. The trends and themes derived from the literature and secondary data influenced the survey questions and the data gathered helped in forming the second phase of the research. The second phase investigates local and global manufacturers' opinions and expertise in the subject, with originality in terms of how screen cost calculations had an influence on the 3DP screen prototype. The developed 3D prototype was then discussed in a focus group in the last phase of the research to obtain feedback and forecasts about the viability of such a product in Bahrain and the Middle East market in the coming years. An in-depth explanation of each method is described and justified in Chapter 3 after examining the wealth of related literature, and a SAFE value theoretical framework is derived to thematically address the research problem and its questions.

Chapter 4 then explicitly describes each method used and why other methods were not considered. It starts by comparing key authors' methodologies in the field of architecture and product development. Thus, the formulation of each method to fit the SAFE framework generated is also outlined in this chapter. Figure 1-3 frames the methodology and data used to influence the findings and responds to the current research questions, aims and objectives. The findings and data results were analysed in Chapter 5 according to SAFE themes and the research objectives. Thematic analysis and metaphor analysis were used to code information from the nine type of methods used in different tasks, see Figure 1-2 . The results addressed research objectives and also produced data that can be looked at as future possible perspectives of the researched 3DPM and its value in sustaining architecture heritage.

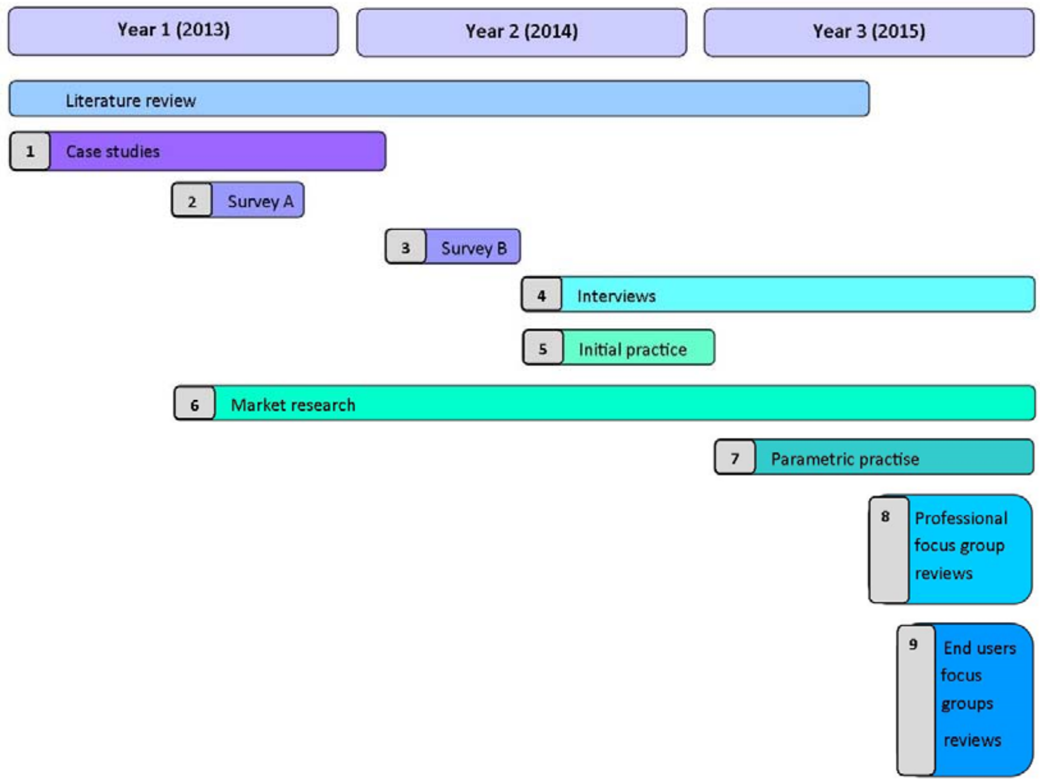


Figure 1-2 Methods tasks and phases. Source: Author.

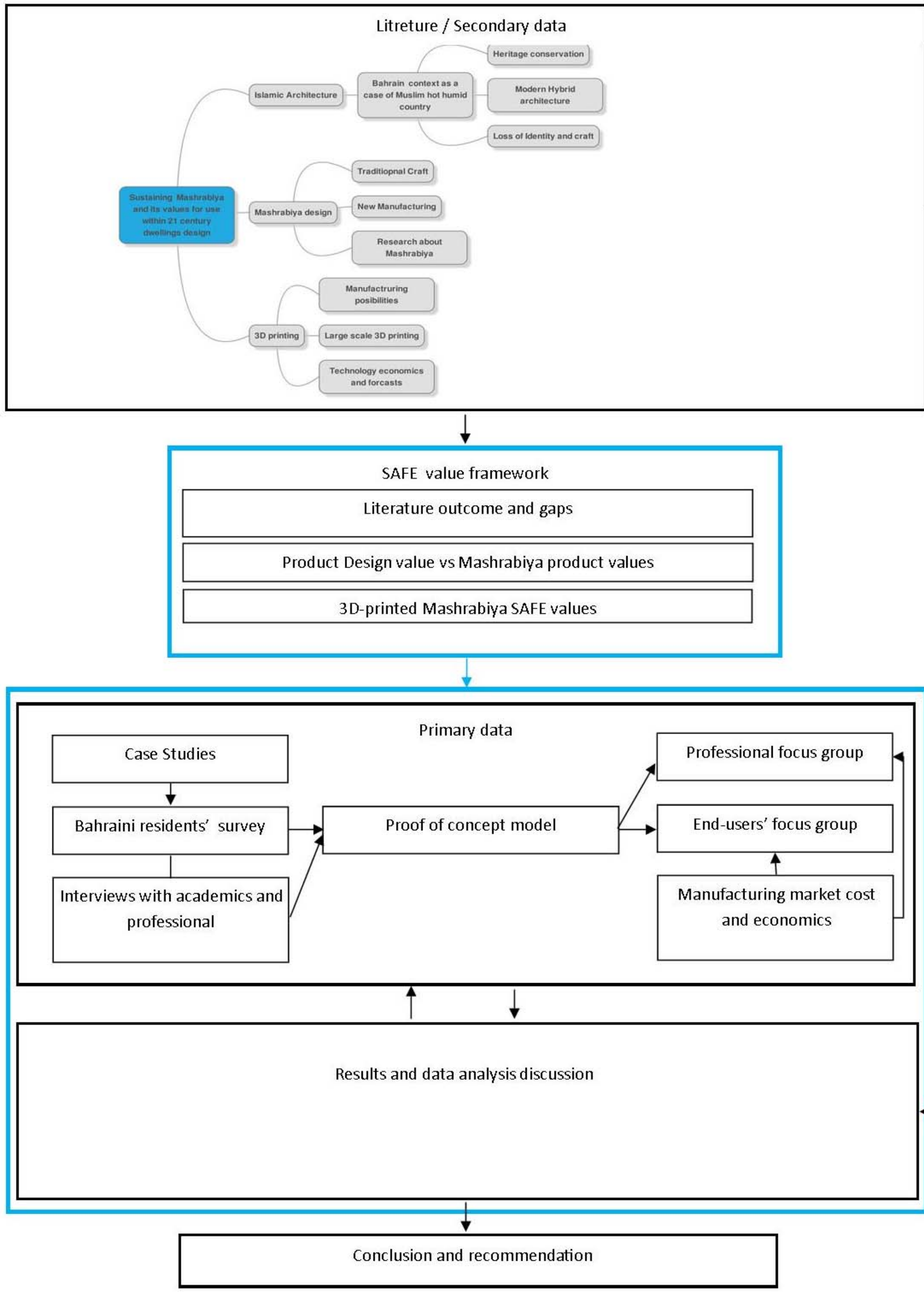


Figure 1-3: Research framework. Source: Author.

1.8 LOGIC SEQUENCE OF THIS RESEARCH APPROACH

The research is formulated in a way that includes the background area topics and scholars' latest work in the fields explained in Figure 1-1 mind map. Figure 1-4 and Figure 1-5 present this in a visual way, and shows how each chapter influences the next.

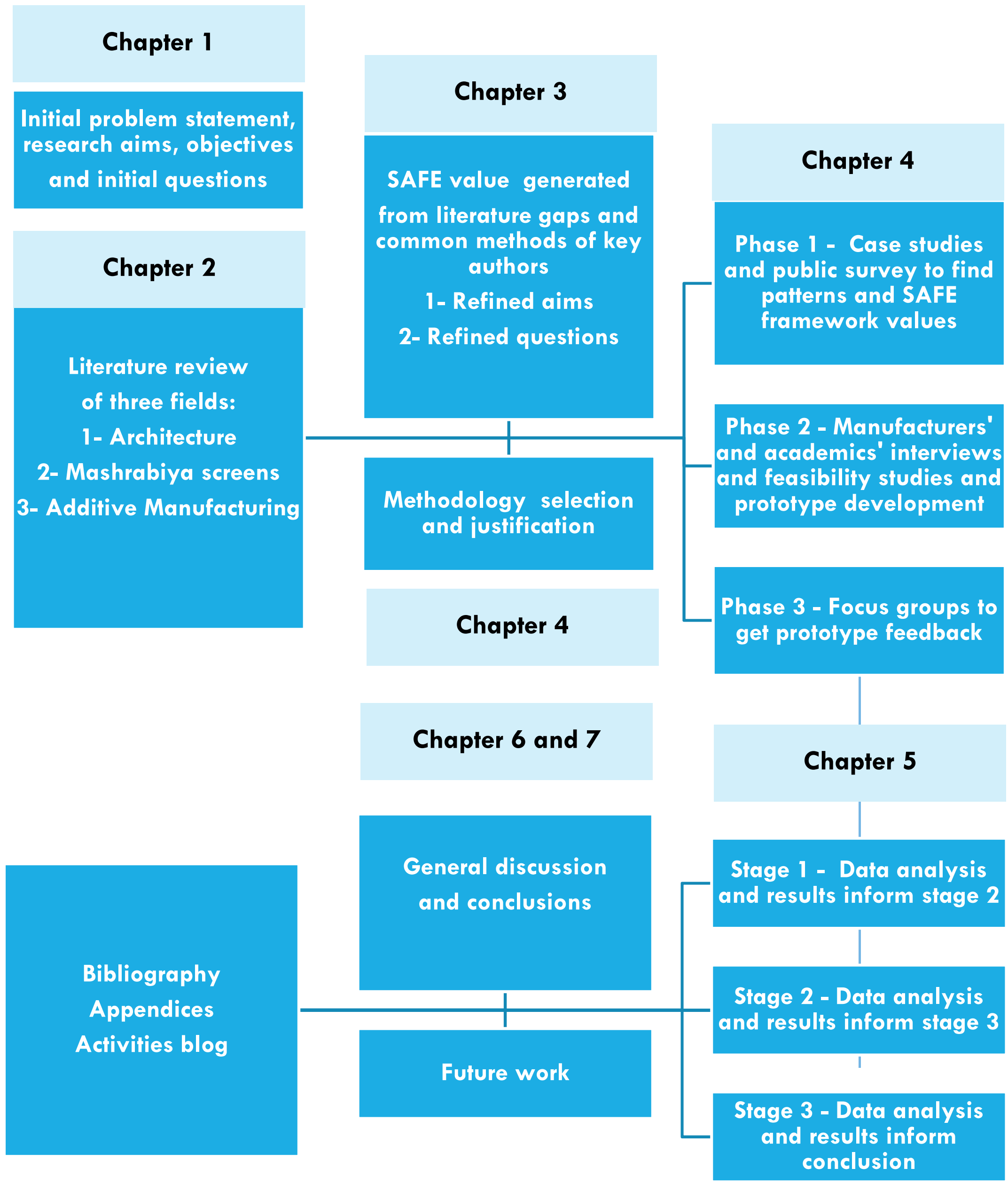


Figure 1-4: Thesis structure. Source: Author.

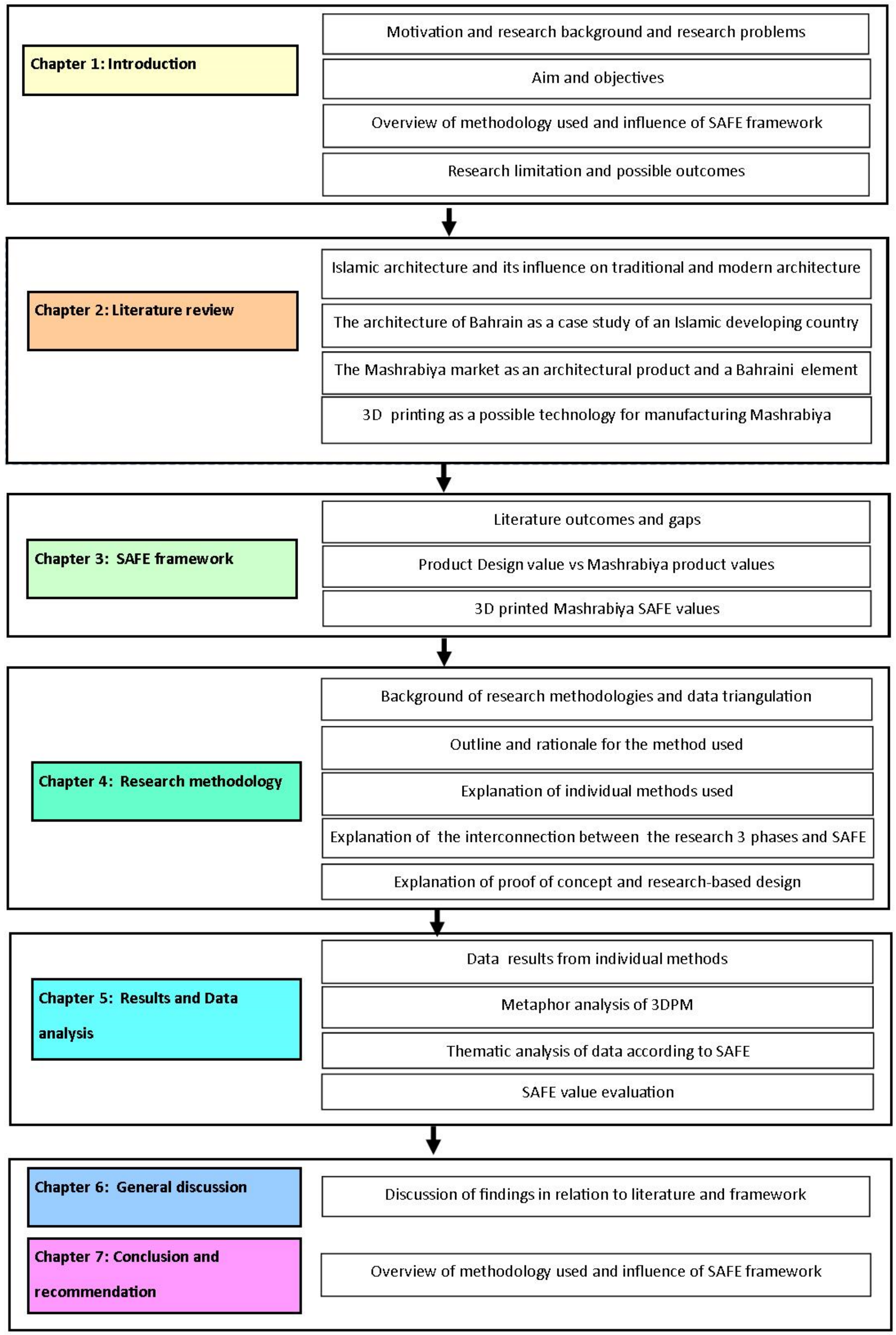


Figure 1-5: Research structure with the objectives of each chapter. Source: Author.

1.9 CHAPTER CONCLUSION

The first chapter presented a general overview of the research undertaken. It provided an introductory understanding of the aim, objectives and methods used to obtain answers to the research questions from the literature and the collected data. It introduced the various disciplines that will be examined within the literature and design practice, and identified possible limitations. The final part provided a visual workflow of the thesis chapters in response to the set aim and objectives. The next chapter will discuss the latest literature about the following topics:

A- **Context**: Arabian Gulf architecture including Islamic values in general and how it is reflected in Middle East architecture. Then it will explicitly focus on Bahrain as a context.

B- **Application**: Mashrabiya as a product of Islamic architectural values, heritage and the Middle East climate.

C- **Innovation**: 3DP as an innovative additive process; it has the possible potential to revive Mashrabiya and replace the current expensive subtractive manufacturing used to make Mashrabiya.

D- **Reflection*:** Conscious and unconscious applications of Mashrabiya as a product and concept in sustaining heritage and promoting a new architectural identity.

The following are tips to read the text of this thesis in the coming chapters:

1- ***Text coding**: Teal-coloured sentences within the body of text are highlighted to indicate a process of reflective and critical thinking. It indicates critical literature absorbed and digested with reference to the research aim and objectives and then discussed to frame new knowledge and innovative research outputs.

2- Graphics, photographs and charts have been taken and produced by the researcher (Author) unless otherwise mentioned.

3- Some charts and tables are a product of intellectual thought and researcher contribution and they will be written in **green.**

CHAPTER 2

"If I was to realize new buildings I should have to have new technique. I should have to design buildings that they would not only be appropriate to materials but design them so the machine that would have to make them could make them surpassingly well."

Frank Lloyd Wright

CHAPTER 2: BACKGROUND AND REVIEW OF THE LITERATURE

2.1 INTRODUCTION

It is crucial to understand and reflect upon the transformation of the Islamic architecture environment in general and the Arabian Gulf region in particular in order to apply this knowledge in the future. Islamic values within Arabic courtyard houses influenced some of the concepts of modern architecture in the Middle East region's design and manufacturing markets. Social values, climatic needs, architectural forms, and facade parameters are products of several former metamorphoses in this culture. It is highly important, therefore, to understand the background of Islamic houses, and Arab houses in particular, to be able to design for the future growth and economic standards within the architecture market. Different sources in both Arabic and English have been used to obtain information about traditional and modern dwellings in the Gulf region. Moreover, general building regulations within the GCC countries as well as local and global manufacturing are taken into account. This chapter consists of a study of the background literature written on topics related to the influence of the climate and religion on the architecture of the facades and window shading devices of sustainable buildings in the Arab and Islamic regions.

As suggested by Almurahhem (2008), the influences of hypermodernity trends and the cultural identity crisis have left remarkable traces to be studied and investigated. The importance of the research topic is strongly influenced by the location and cultural constraints in Bahrain as a developing GCC country. The researcher's background, as a Muslim citizen of one of the GCC countries, Bahrain, provided her with the tools to review, analyse and articulate information about the different highlighted subjects as a citizen of the Bahrain society and as an observer of the architectural language shift and its influence on heritage preservation.

Section 2.2 of this chapter describes the historical, traditional values and Islamic regulating rules that governed the design of Islamic houses. Following this a summary is provided of the building components within courtyard houses, the materials used and the social and aesthetic characteristics of traditional houses. Bahrain, the smallest GCC country, is chosen as the focus for this in-depth case study and research fieldwork. Due to its relatively small size and the researcher's familiarity with its architectural scene, Bahrain is an ideal context for comprehending the industrial market and common manufacturing practices. General issues related to history, climate, culture and economic status will be used to understand the traditional and current architectural trends related to buildings and their facades. Window design regulations and their treatment will be a particular focus of this research, as documented in section 2.2.3.

The Mashrabiya is a product of a highly complex culture governed by religious, social and environmental constraints. It has been selected as a context for this research as it can still sustain the culture-social identity and architectural identity by using modern technologies. More investigation about Mashrabiya history, materials and current advancement are documented in section 2.3. The social, aesthetic and functional as well as economic constraints of Mashrabiya production will be investigated in the sub-sections of section 2.3 to understand its current uses and new innovations. There are gaps in the existing knowledge relating to manufacturing techniques and the cost estimation of this product that this research aims to fill. Moreover, it is important to be aware of previous and current Mashrabiya manufacturing techniques and the use of modern Mashrabiya products in current projects.

The Mashrabiya is a large-scale product of the architecture, interior design and manufacturing industries. The construction of old Mashrabiya using traditional manufacturing and manual skilled labour is at its end because of a lack of skilled craftsmen. Instead, digital fabrication, CNC and CIM milling, rapid prototyping or 3D printing and AM is at the forefront of current production techniques. The research focuses on the possibility of producing AM Mashrabiya as a solution to the obstacles faced by local manufacturing techniques, as identified in sections 2.3.6-2.3.10.

Section 2.4 provides a coherent understanding of 3D printing manufacturing possibilities. 3D printing as an additive process is different to subtractive manufacturing, as can be understood in section 2.4.2. A new global market, new benefits and obstacles are discussed in detail in sections 2.4.4-2.4.7. It also presents conceptual and real projects and products that use the Mashrabiya concept yet revive it in a new way.

Triangulating the literature from Islamic architecture, Mashrabiya design and past production to current additive manufacturing possibilities can aid in producing a new sustainable Mashrabiya. However, a set of valid values that have always been associated with Mashrabiya should be analysed and developed after conducting this literature review.

2.2 ARABIAN GULF ARCHITECTURE AND THE BAHRAIN SCENE

2.2.1 ISLAMIC ARCHITECTURE IN THE MIDDLE EAST

Islam as a religion is based upon five pillars: the first is the belief in God almighty, then prayer, *Zakat* “charitable giving”, fasting during the month of Ramadan, and performing the pilgrimage to Hajj at least once in your lifetime. Based upon these religious pillars, the ‘divine principles of Islamic architecture’ emerged. Mustafa (2008) outlines these principles as the following: Unity (*Twawhid*), Respect (*Ihtiram*), Sincerity (*Ikhlas*), Knowledge (*Ilm*), Balance (*Iqtisad*), Modesty (*Haya*) and Remembrance (*Diker*).

Since the 7th century, Muslims around the world have practised the Islamic religion that promotes unique teachings, rituals and practices. Islamic architecture can be defined as the architecture that originated from Mecca in Saudi Arabia, following the religion of Islam taught by Prophet Mohammed, peace be upon him (PBUH), the messenger of Almighty God. It spreads all the way from China and India in the East to Spain in the West. Akbar (1984), Almurrahem (2011) and Aljawder (2014) explain how the Quran, the Muslim holy book, traditions, the Sunnah or Islamic morals, and the advice and actions of Prophet Mohammed (PBUH) govern every aspect of Muslims’ personal etiquette, daily life routines and building designs, which comply with Moustafa’s (2008) previously mentioned principles. Rabbat (2012, p.15) defines Islamic architecture as:

> *“… the architecture of those cultures, regions, or societies that have directly or via some intermediary processes accepted Islam as an integral component of their epistemological and socio-cultural makeup.”*

Ibrahim (2012) and Moustafa (2008) also indicate that Islam shapes specific ideas and lifestyles in dwellings and other architectural forms. Muslims believe that the Quran and the Islamic tradition express timeless truths that should enlighten human action and thought. Grand Mosques in Turkey, Spain, Iraq, Iran and Egypt are standing examples of worship through design. Moustafa (2008) explains that an example is the use of repetitive patterns and verses from the Quran in the interior treatment of mosques as a means of worshipping through remembrance.

Wally (1993), Yassin and Utabarta (2012) distinguish four important Islamic periods. The Prophet Mohammed and his succession of companions in the early period were characterised by having a simple lifestyle and modest living devoted to worship and the spread of the religion. The following period was the Umayyad dynasty in Damascus, Syria, who were notable for their lavish palaces and attention to decoration. The Abbasid golden era followed with distinguished minarets, inheriting and developing ancient architecture from Babylon and Mesopotamia and adding to the distinguished architecture in the region known today as Iraq. The magnificent Ottoman Empire marked the last of the Islamic golden ages in architecture. The quality ranged between beauty, complex structures and domes, with a high value placed on privacy. This was achieved through the use of Mashrabiya, or *Kafe*, as noted by Sedky (1999), as window covers to the distinct male and female quarters known as *Haremlik* and *Salamlik*, respectively.

The values that influenced Muslim lifestyle and Islamic dwellings were related to aspects of simple human nature like personal privacy, and no-harm values. As Alaali (2006) describes, Islamic architecture, like any other architecture, was composed from the environment, the soul and the mind. He elaborates by explaining that the sensory environment of the site, climate, material, colour and the human body are all parts of the environment. The soul is evident in the design of modest buildings that try to capture inhabitants' feelings and emotions. Furthermore, the mind is set to understand the philosophical reasoning behind religious architecture.

Inward-oriented courtyard houses, the covering of womens' heads and bodies, the veil or Hijab, segregated male and female quarters, the importance of visual privacy, as well as the importance of neighbours' rights, are a few examples of Islamic architectural forms and values. Some of these values will be explained in this research in their related context. The courtyard houses of the Middle East and GCC countries will be analysed in the next section, section 2.2.1. Moreover, the importance of visual privacy and women is explicitly examined in section 2.2.2.

In brief, the Islamic house was designed to serve several immaterial criteria of its values, like visual privacy and its reflection of inward architecture preferences. In an in-depth study by Akbar (1984) about the responsibilities of Muslims within their built environment, the phrase 'Neither Darar Nor Dirar' was found to be highly important. This quotation is a tradition expressed by the Prophet (PBUH) and is translated as "there should be neither harming nor reciprocating harm" or "there is no injury nor return of injury". According to the Abu Dawud reference (cited in Akbar, 1988, p. 202), which is one of main five principal traditions on which jurisprudence (*fiqh*) is based, this means that no person should harm or damage another by word of mouth, hands, ears or even building design (Sidawi, 2012). This was evident during the ruling of Caliph Umar in a case in which a Muslim man constructed a room on the upper floor of his home and opened a window that overlooked his neighbour's home. Aljawder (2014) argues that preventing the gaze in Islam applies not only to other people and to their private parts, but also to the private territory of other people's houses. Caliph Umar demanded that someone test and step on a bed and look through the window to ensure the neighbour's right of privacy. If the inspector saw what was in the neighbour's house, the window was ordered to be sealed, told Al-Lakhmi (d. 478/1085). Hakim and Ahmed (2006) categorised five main rules adopted in daily life matters and in Islamic building design (see Figure 2-1).

Almurrahem (2008) states the importance and obligation of asking for permission before entering a Muslim house. This is due to the architectural concealment given to Muslim veiled women in order for them to act with freedom and to have privacy, as they cannot remain veiled both inside and outside. Muslim women follow the role of modesty and adhere to the Hijab role as a veiled garment and respectful act that conceals feminine physiques from the gaze of outside men. It is recommended for privacy to be achieved around the world, but Alsurf (2012) states that it must be achieved in Arab Muslim houses, like in Saudi Arabia and Bahrain, and is also compulsory in Kuwait, according to Alenazy (2007). The use of window screens that provide a visual connection from the inside to the outside and not vice versa, are widely used in such countries. There are variation in their name and construction, from the Rawashen of Jedda, to the Shanasheel in Iraq, to the Mashrabiya in Egypt.

1- Harm should be eliminated. (A2)
a) Do not harm others, and others should not harm you. (U, A1)
b) It is mandatory to commit to the lesser of two harms. (M)
c) Harm must not be alleviated by an equal or greater harm, but by a lesser harm. (A2)
d) Repulsion of evil should be addressed before inviting goodness. (A3, M, I)
e) If two evils are confronted, one affects religious matters and the other is worldly in nature, the priority should be to repulse the former. (A3)
f) If two evils are confronted, one is greater than the other, the priority should be to repulse the former. (A3, I)
g) Sometimes a prohibition might be allowed to avoid a greater one. (M)
h) Repulsing evil for ushering goodness is encouraged. (M)

2- Affairs are determined by their intent. (M)
a) Deeds are judged by their intentions. (A1)
b) Concealment of defects is deception, and that is prohibited. (I)

3- Certitude cannot be dismissed by doubt.
a) The basis is for allowance. (M)
b) A doubtful condition cannot be used for assigning responsibility. (I)

4- Hardship ushers relief. (M)
a) After confinement there is accommodation. (A1, M)
b) To avoid difficulties, the Shari'a allows many pressing necessities. (A1)

5- Custom has the weight of law.
a) Convention has ascendancy. (M)
b) Rules differ in response to different conditions and times. (A1)
c) Each era ushers in new conditions, which necessitates its own requirements. (M)
d) Whatever new changes occur in customs should be recognized, and whatever is abandoned should not be recognized. (M)
e) Rules based on a custom change with changes in that custom. (I)

١- الضرر يزال
• لا ضرر ولا ضرار
• وجوب إرتكاب أخف الضررين
• الضرر لا يزال بضرر أشد منه أو يساويه وقيام لزم إرتكاب أخف الضررين
• درء المفاسد مقدم على جلب المصالح
• إن تعارضت مفسدتان إحداهما دينيه والاخرى دنيويه فدرء المفسدة الدينية أولى
• إذا تعارضت مفسدتان إحداهما أكبر من الاخرى فدرء المفسدة الكبرى أولى
• قد يباح الممنوع لتوقع ما هو أعضم منه
• يسوغ لدفع مفسدة تجلب مصلحة

٢- الامور بمقاصدها
• الاعمال بالنيات
• كتمان العيوب غش محرم

٣- اليقين لايزول بالشك
• ما أصله الاباحة
• الشك في الشرط مانع من ترتيب المشروط عليه

٤- المشقة تجلب التيسير
• ما ضاق شيء الا اتسع
• أباح الشرع كثيراً من الضرورات لنفي الحرج

٥- العادة محكمة
• العادة غلبة
• تختلف الاحكام لاختلاف الاحوال و الازمان
• لكل زمان أحوال تتجدد و إقتضاءات تتعين
• مهما تجدد في العرف أعتبر و مهما سقط انتقض
• الحكم بالعادة يتغير بتغير العادة

Figure 2-1: Islamic Rules Qawa'id Fiqhiya in their original Arabic and English translations grouped by the five central Qawa'id. Source: Hakim and Ahmed (2006, p. 5).

Additionally, the traditional Muslim house had several means to privacy. Ani (1994) states that they consisted of separate staircases and entrances used to ensure the privacy of women from guests, and the segregation of male (Salamlik) and female (Haramlik) public quarters. The number of courtyards within a house, depending on the owner's wealth, encouraged an inward emphasis on decoration. There was segregation of women's private life from the gaze of outsiders. Islam emphasises privacy, modesty and chastity for both women and men. Mortada (2011) assures that gazing at individuals and buildings in Islam carries with it definite limits and conditions, as noted earlier by Akbar (1988). Therefore, gazing is always conditional, and ordinarily must be avoided, especially from facade windows. Facade treatments of Muslim houses remained simple and modest (Yarwood, 1998), yet there was an emphasis on ensuring that the openings were covered so as to not allow people to gaze into neighbouring houses.

Women within an Islamic interior were highly valued. Kotnic (2005) notes that women moved freely even through exterior space if they veiled their bodies, permitting only their social class to be recognised. “The anonymity of the veil renders women visible, but they cannot “be seen” by men, for in Arab societies, seeing is defined as a socially determined activity, not merely a physiological process” (Gilsenan, 1982 as cited in Kotnic, 2005, p. 480). Therefore, he claims that the veil functions as a “movable interior space” to allow women to infiltrate exterior space.

Furthermore, the concept of the *ḥarīm* and *haramlik*, defined by Almurrahem (2011) as the inner space in the Islamic and Arab house, is well known by Orientalist painters and Western architectural scholars, but its true essence is unknown. She argues that the image of the ‘*ḥarīm*’ in the minds of Orientalists remains like a scene from Arabian Nights, one to be perceived and adored, without them having a full understanding of the existing culture and religion behind it.

Islamic architectural characteristics vary over the Islamic region and within the scientific renaissance that once distinguished devoted Muslim scholars. Yassin and Utabarta (2012) describe that varying characteristics from region to region metamorphosed to serve the climate, architecture and cultural heritage of the Islamic region. It is important to note here that the term ‘Islamic Architecture’ as defined by Rabbat (2012) widely overlaps with ‘Arab Architecture’, to which the call of Islam was first sent and the Quran was written in the Arabic language. Raggette (2012) defines ‘Arab Architecture’ as the architecture of buildings that stands in the whole Arab region fro the Atlantic to the Gulf .Briggs (1974), for example, used the term ‘Mohammedan Architecture’ in his book titled *Mohammedan: An Architecture in Egypt and Palestine* because of the overlaps between Islam and Arabs.

Nevertheless, Elshorbaji (2010) claims that the socio-cultural differences in each region were absorbed into a common architectural language. It was a sustained language that responded to arid zones and climate and still satisfied religious needs. The harsh hot and humid desert environment, especially in GCC countries, is a non-deniable piece of sensory evidence. Wally (1993) also proves that traditional indigenous architecture was a successful endeavour as buildings were built to respond to climatic and human needs, and constructed to exist within the harsh yet Islamic environment.

In conclusion, the above overview of Islamic culture and its values shows that it can shape not only the facades of houses but even the product it functions within. Understanding religious drivers, human nature and climatic conditions is a key factor in successful design within Islamic interiors or architecture. Elshorbaji (2010) concludes that every architectural element in the Islamic house used to represent a solution to a diverse problem that appeared due to a specific condition. However, time, the economy, globalisation, materials and manufacturing technology imposed a new Islamic architectural language and values. This metamorphosis is the basis of the current debate in the Islamic Arab world, which changed significantly after the new economic status brought about following the discovery of oil. Factors, forms and the transformation of traditional to modern architecture within GCC countries all have great significance. The subjects of modern architectural identity and facade treatments have been the research focus of many scholars such as Akbar (1994), Ben Hamouche (2004), Dayaratne and Karajica (2007), Dayaratne (2012) and Abdelsalam and Rihan (2013). The following section discusses this in more detail. It starts by providing a general overview of the current situation in the architecture of the GCC countries. Following this, it concentrates on Bahrain as the context of the research.

2.2.2 The Middle East and the GCC countries

TRADITIONAL ARABIAN GULF ARCHITECTURE

The Middle East is a vast region that spans an area from Egypt to Western Asia, including within it the Arabian Gulf countries. The Gulf Cooperation Council Countries (GCCC) include Bahrain, Oman, Kuwait, Qatar and Saudi Arabia. Islam is the most practised religion and Arabic is still the common language of the citizens, as well as other languages being spoken such as English, French and Persian. The language mixture is inherited from the historical Persian Empire, the Ottoman Empire, and even the British and French colonies that once ruled part of the Middle East. The interrelationship between Islamic values and Arab architecture can be noted in what are titled in the literature as Arab, Muslim, or Middle Eastern houses (Ani, 1994). For the purpose of unity, traditional Islamic Gulf architecture will be focused on to understand the courtyard house forms and characteristics in the hot and humid climate around the Arabian Gulf.

Alenazy (2007) and Dayaratne (2012) state that building design, identity, culture and manufacturing techniques in the Middle East changed after the discovery of oil, especially in countries in the Gulf region following the 1930s. The introduction of electricity and extra wealth made it easier for modernity to take off layers of advanced vernacular architectural dwellings, which were replaced by concrete buildings. Ghiasvand (2008) questions current Islamic architecture identity, he claims that most of the Islamic countries today are at the crossroads between retaining Islamic traditions in architecture and a new version of modern architecture with the spirit of Islam.

This part of the research can be considered as an introduction that contextualises the traditional Arab architecture within GCC countries, discussing its original form and the changes it has gone through to recent times. Two types of buildings will be in focus: traditional houses or courtyard houses, and traditional ventilation systems, particularly window treatments. Kotnic (2005) found that courtyards are deeply rooted in the architectural history that was fully developed in the Sumerian city plan of Ur around 2000 BC. In addition, Elshorbaji (2010) backdates the courtyard to the Graeco-Roman tradition (c. 1900 BC) in Arabia. Moreover, Alenazy (2007) relates the concept of an open courtyard to that of the patio in Spanish or Spanish-American houses. With the arrival of Islam (632 AD), the concept of the courtyard was adopted by Muslims because it was suitable for their religious and social needs, especially in terms of the degree of privacy needed.

As Ajaj and Pugnaloni (2014) indicates, most of the courtyard houses were situated in irregular plots within an indigenous and organic urban fabric. The main component was a central courtyard that served both a social and a climatic function in ventilating the interior of the house. Room arrangements and passageways surrounded the courtyard. The number of courtyards within a house reflected the wealth of its owner, with wealthier owners having a higher number of courtyards (Yarwood, 1988). Generations of the same family lived together in courtyard houses in different quarters, with multi-function rooms. The focal point was the courtyards that can be considered as being representative of gender and sexes. For example, there might have been a female courtyard and another for servants in wealthy houses. The courtyard was a social space that family members would use to sit in and watch their children, and women would use to chat and to drink afternoon tea.

The benefits of the courtyard have been endorsed by several scholars. Elshorbaji (2010) and Ajaj and Pugnaloni (2014) explain that a courtyard could provide adequate climatic and social solutions. It also provided privacy and shading in an open space. The courtyard hosted most of the daily house activities. Al-Hussayen (1995) as cited in Alenazy (2007) indicates that from an environmental point of view, the courtyard functioned as a thermal regulator. Small courtyards benefitted from the height of surrounding rooms and walls. Between the cool night air and hot afternoons, the air cycled and descended accordingly to surrounding rooms. Courtyards radiated heat to the cool night sky while during the afternoon convection currents functioned like a chimney (Ajaj and Pugnaloni, 2014). Alenazy (2007) notes that the passive cooling effect was enhanced by the external wall of the house being shared with neighbouring houses, thus minimising the exposure of vertical surfaces to hot sunrays. The air temperature, humidity level and visual comfort were also modified by the courtyard's simple landscaping. Unlike Persian, Syrian or Iraqi courtyards, Gulf courtyards avoided the use of pools and fountains as these might increase the relative humidity (Safarzadeh and Bahadori, 2005).

According to Al-Hussayen, one of the courtyard's vital functions was its social role. It made life easier for women inside it to perform their domestic duties free from the gaze of outside men. Thus, it became a vital dynamic space concealed from outsiders (Lewcock and Freeth, 1978). Ani (1994) expresses a contradictory argument by stating that this practice was extreme and forced women inside, reinforcing their dependence on the men. She opposes the social vertical hierarchy manifested from the ground floor to the first floor. She explains that in the case of Iraq, spaces on the ground floor were mostly used by men; the upper floor was occupied by women. On the other hand, Almurrahem (2011) justifies the need for such a female (Hurma) quarter, or *Harim*, derived from the Arabic word *haram*. Haram embodies the concepts of protection, respect, sacredness, religious limits and rules to be achieved in practice and acknowledged. Therefore, Muslim houses are mostly considered as being respectful of such feminine places as they have their own Hurma or sacredness, see Figure 2-2.

Types of privacy	Location	Design considerations
Visual	External	1. Doors: Entrance doors are placed away from the main street and not directly facing the opposite neighbors 2. Windows: a) Above eye level windows (approximately 1.75 m high) at lower floors with small openings; b) Higher level windows with timber lattice screens (*mashrabiya*) 3. Building heights: Similar building heights and windows are not directly facing opposite neighbors
	Internal	1. Courtyard: Providing microclimate and direct visibility into neighbors' internal home spaces 2. Gendered spaces: Separation of male and female guest areas to maintain privacy and safety for women
Acoustical	External	Floors, walls and roofs should not allow penetrations of voices to neighborhood dwellings and streets, especially women
	Internal	Thickness of walls and dense materials, such as mud bricks, stones and rocks are used Internal spaces are divided into three zones to achieve privacy: male, female and service (linked through courtyard)
Olfactory	Internal	Oud (agarwood) are used as incense to disinfect the house and control smell from cooking odors reaching guests

Figure 2-2: Type of privacy within traditional Muslim houses. Source: Othman (2013).

In this assessment, the female or Harim quarter or zone is a gender-oriented space that represents the governing of the role of the Islamic veil (Almurrahem, 2011). During the Ottoman period, this quarter was referred to as the *Haremlik*. Due to this fact, the architecture of such a courtyard style and the female quarters meant that this architecture type was labelled the 'Architecture of the Veil' by Kenzari and Elsheshtawy (2003), Ghiasvand et al. (2008) and Sidawi (2012). The veiling of not only the female body but also openings such as windows using Mashrabiya is a coherent production result of such conservative Islamic design practice.

The inward orientation and beauty of Gulf courtyard houses is reflected in their exterior treatments. Ajaj and Pugnaloni (2014) states that this allowed simplicity and minor variation in external facade treatments to be a common feature. Samuels (2011) notes that the role of the main facade form and openings was to ensure privacy and block the summer sun and reduce internal solar gain, yet allow a small quantity of light to penetrate during the short cold winter months to the living zones.

Traditional houses are oriented with respect to the prevailing wind. Wind towers, Malqafs, or badgirs were accounted for by Fathy (1986), Kazerooni (2002), Khanghahi (2011) and many others as main natural ventilation features used within Gulf houses in support of the courtyard function.

Furthermore, Vakilinezhad et al. (2013) indicates the significance of protecting the openings from hot dry winds, dust and sand. Consequently, the importance of avoiding glare arises as the amount of solar radiation is relatively high, especially for west-facing windows (Ajaj and Pugnaloni, 2014). A further necessary function of the openings, together with their shading and veiling functions, was to block noise, as suggested by Ibrahim (2012) and Kazerooni (2002).

Form can follow material in Gulf courtyard architecture. Eldemery (2009) refers to the fact that vernacular architecture in the Islamic world came as a suitable response to the harsh living conditions of the natural environment, using local building materials and appropriate techniques of climate control. Alenezy (2007) lists the main materials used as including bricks of adobe clay, sea rocks; gypsum, mud or seashore rocks mortared with mud; and imported roof timber or local palm tree trunks. Hui (2005) states that the local materials were chosen “not for the nostalgic romance only, but rather a scientific and realistic solution to the special design problems in that area”. From a budgetary point of view, Ajaj and Pugnaloni (2014) clarifies that the traditional building techniques employed were rarely costly in terms of energy or materials. He emphasises the fact that materials were within the economic grasp of local people, who Hui (2005) classifies as being of poor economic condition. This is not entirely true for all classes and regions of the traditional Gulf countries; Bahrain, for example, was one of the richest countries due to its high income from leading the pearl diving industry until the production of artificial pearls by the Japanese.

Pearl diving, fishing and agriculture were the main industries at the time. Pearl merchants of double or triple courtyard houses differed from Parasti or palm tree poor fishermen huts. However, the housing style changed tremendously, as well as the landscape and architectural skyline, after the fall of pearl diving and the discovery of oil within Gulf countries after the 1930s, see Figure 2-3. Electricity and modern transportation as well as the advancement of the education system, upgraded Gulf Architecture to a new level that will be discussed next along with the factors effecting these cities. Abdulsalam and Rihan (2013 p. 160) defines the reasons for this as follows:

a. Development that resulted from foreign interventions during the 19th century.
b. Development that resulted from technology transfer influenced by industrialisation.
c. Development that resulted from the fast rural–urban migration after the Second World War.
d. Development that resulted from the sudden inflow of oil wealth during the 1970s.

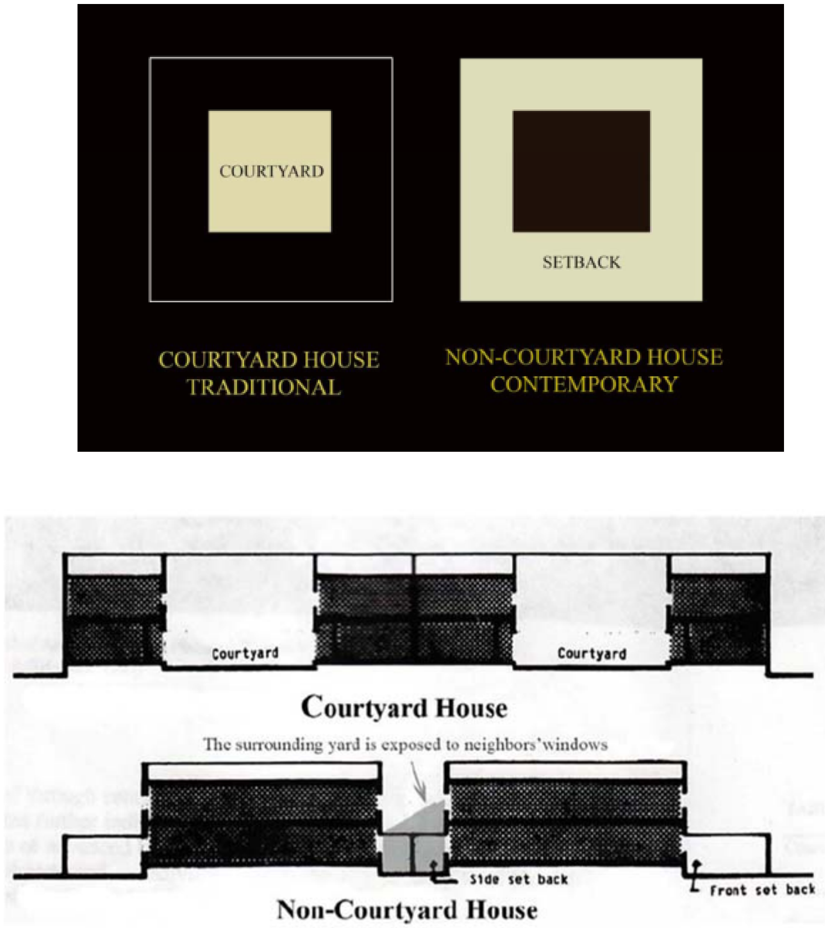


Figure 2-3: A comparison between the courtyard traditional Gulf house and the contemporary house.
Source: Alenazy (2007, p. 36).

MODERN GULF ARCHITECTURAL IMAGE

The past eight decades of Gulf architecture have significantly affected the social and spatial form as well as the facade treatments of houses. The facade image has significantly changed from adjacent wall-to-wall courtyard houses to central villas with side setbacks. As Wally (1993) notes, the uniqueness of courtyard houses in terms of fulfilling individual needs and the urban social context changed to an owner-oriented modern house design to show oil-earned wealth and class. A solemn observation by scholars was that architects were tempted to 'pick' Western house designs 'off-the-shelf', as claimed by Akbar (1988), and to start a 'copy' and 'paste' of Western elements into modern Gulf houses, as highlighted by Sidawi (2012) and Ajaj and Pugnaloni (2014). Table 2-1 categories the major stages that modern Gulf architecture went through, compiled through several notes and design codes found in Gulf literature.

In a very recent review of the literature regarding Muslim houses, Othman et al. (2015) define three influential design values that were inherited from traditional houses. Like Akbar (1984) and Sidawi (2012), Othman et al. (2015) emphasise that Muslim homes are still subject to guidelines from principles drawn from Islamic law (Sharia), which are derived from the Quran, Hadith and traditions mentioned earlier. Holistic values are outlined as Privacy, where the home is defined as a private and safe place for personal and family sanctuary. The second is Modesty, where a home should have spaces for religious activities and rituals, further characterised by humility in design through sustainable and economical designs. The third is Hospitality, with a high value placed on houses that extend hospitality and respect to neighbours and which enhance relationships with society.

Nevertheless, it can be claimed that the resulting architecture of Islamic Gulf cities do not respond to Islamic building laws (Sidawi, 2012). Table 2-1 describes how inhabitants strive to show off new facades and lavish decoration that could be afforded after the oil discovery raised incomes. This contradicts the Modesty value. The privacy of windows and interiors were also subject to new trends, as new materials and styles emerged and the image of the traditional concealed facade was considered to simply be that of the past.

In a recent architecture movement to raise awareness, sustaining heritage and maintaining local identity have been the driving force of change in many Gulf cities (Dayaratne and Karajica, 2011). Many local and regional initiatives and scholarly articles have raised awareness of the importance for new modern architecture to build upon traditional modelling techniques. Some of these movements include the achievements of Bahrain's Ministry of Culture, the efforts of Saudi Arabia's Prince Sultan bin Salman towards sustainable heritage and the United Arab Emirates' heritage and conservation annual conference.

Table 2-1: Stages of Bahrain and characteristics of Modern Gulf houses. Source: Author.

Period	Stage	Authors	Characteristics	Positives	Negatives
Before 1950	Pre-Oil	Ani (1994)	Simple palm houses. Courtyard houses. Influenced by British colonies.	Respected Islamic law and environment, gave privacy to women and maintained their identity. Form follows economic status and material availability.	The houses of lower-class inhabitants were less distinctive.
1950s - early 1960s	Early Post-Oil	Alenezy (2007)	Geometric facades, sloping roofs, spacious balconies. Air-conditioned interior spaces. Exterior materials were cement plaster, stucco, and natural stone.	Air conditioning allowed enlarged window openings.	Exterior shading devices minimised and traditional ones disappeared, like Mashrabiya.
Mid 1960s - 1970	Middle Post-Oil	Ani (1994), Alenezy (2007), Dayaratne and Karajica (2011)	Palladian-style villa was associated with aspiring to a higher social status. Copy-paste of Western architecture emerged.	Uneasy presence of symmetry, elaborate domes, resembled Western cities that Gulf locals travelled to. Balconies had been either reduced or eliminated.	Used as a symbol of power and prestige, to expose wealth to the outside and exhibiting an increasingly popular seduction trend.
1970s - 1980s	Late Post-Oil (Increase in oil prices)	Alenezy (2007)	Independence and oil wealth oriented towards modernism. Yet, locals started increasing the functional performance of Islamic courtyard architecture.	Traditional Islamic architectural elements such as courtyards and lattice screens inspired housing designs.	Social housing imitated a form of traditional identity and not its functions. Iron and aluminium grills and wooden shelves used.
1990 - 2000	Gulf War	Mahgoub (2008)	Slow and cautious development in construction. Focus on infrastructure.	Architectural search for lost identity.	Importance of window safety and privacy. Masking tape used in X shape to stop glass from shattering if bombed.
2000 - 2010	Hybridity and Globalisation	Abdelsalam and Rihan (2013), Radhi (2008), Dayaratne (2011)	Trendy glass technology with high thermal performance and PV and energy reduction systems.	Fast growth in the architecture and manufacturing markets and rapid ideal-image housing by development projects. Initiating solar radiation and energy guidelines.	Designed to follow individual tastes, market forces and popular perceptions.
2010 - 2020	Sustainability	Dayaratne (2011), Abdulsalam and Rihan (2013)	LEED certificate building knowledge, solar and energy efficiency needed.	Awareness of identity, social context and heritage. Experimentation into new fabrications and facade technology. Solar radiation and energy conservation guidelines implemented.	Costly technology. Experimentation for aesthetic purposes.

From an insider's perspective, Wally (1993) associates the loss of local identity with several factors. The first factor involves the transformation of houses into an economic product. This is evident by looking at the post-oil stage in Table 2–1. The second factor involves the loss of social consciousness, seen in the change of individual social structures and families as well as the official urban planning decisions of municipalities. The third factor is a highly influential factor seen in the design dilemma of Arab architects and designers, who design for the sake of the return cost instead of having a real understanding of local and traditional values. Wally defines the last factor as 'dependency'. Wally (1993) claims that this is evident in the reliance on first a Westernised housing unit model and second the dependency on the current manufacturing market. It is thus evident that current housing in the Gulf region is not representative of true Islamic values.

This arises from the fact that the form has not been generated from values but rather resulted from using current manufacturing materials like glass and adapting alien Western architectural models. To support the understanding of this dilemma, a new movement to enhance local identity and values has emerged. It is defined by Abdelsalam and Rihan (2013) as 'sustainable architecture trends' and is categorised into three distinctive trends:

1- The modern trend; followers of this trend in the Arab world adopt recent Western technology and its advancements in dealing with sustainability principles.
2- The neo-traditional trend; followers of this trend need to understand the values of traditional architecture rather than just copy and pasting its elements. The first approach, adopted by Hassan Fathy (1986), relies on understanding the values of the architectural legacy and its experiments. The second approach is an absolute adaptation of the architectural model of traditional buildings with no development of this model.
3- Contemporary interpretation trend; followers of this trend express the traditional design approach in a contemporary way using current modern technology. The aims of this trend can be best defined as being between the neo-traditional and modern trends. Masdar City's Mashrabiya screens made with GRC is an excellent example of the screen in a modern context.

The third trend is of major importance to this research, as digital technology and digital craftsmen are frequently replacing the skilled craftsmen who once governed the designs and production of Mashrabiya screens. Further discussion of these trends in relation to Mashrabiya in particular will be examined in section 2.3.

The following section represents scholars' and architects' calls for change within their field. Promoting better understanding of current problems and aspiring for change are claimed to be needed to reach a future stage of indigenous architecture with sustainable Islamic values (Ben Hamouche, 2004).

CALLS FOR CHANGE

The economic growth following the discovery of oil accelerated development and globalisation and generated new morphologies in the Gulf region. This is noted by Ben Hamouche (2004) as a shift from 'endogenous' to 'exogenous' types of urban growth. In architecture and design, a similar shift has also been noticed in the move from 'traditional' to 'neo-traditional' to 'contemporary-oriented' trends, as discussed by Abdelsalam and Rihan (2013). As Dayaratne (2008) argues, the intimate relationship within Gulf cities between the built environment and Islamic cultural values has been fractured.

The implications resulting from such rapid development have affected architectural identity, heritage conservation, energy conservation and lighting quality issues within modern houses. Values of privacy, for example, have been violated in certain cases, as researched by Sidawi (2012) and Aljawder (2014). This has generated alerts for governments and building authorities to take action to bring about more cautious development. Through examining the literature of the last decade, architects' and scholars' recommendations and calls for change within the built environment can be outlined as follows:

1. Albaher (1985) as cited by Alenazy (2007) relates the loss of identity to both designers and Gulf citizens, Kuwaitis, in his example. The flow of Arabs and people of non-Arab nationalities to work and design within Gulf cities led to the possibility of spreading confused thoughts over architecture as most of these people do not understand the real values. It is therefore the owner's responsibility to ensure that a social and functional requirements list is fulfilled by architects or Westerners who are not well acquainted with these values.
2. Wally (1993) equates the role of the Muslim architect to that of a God worshipper in terms of his role in design according to Islamic rules, values and principles. Architects should take care while designing and not favour modernity aesthetics and ignore real values and social understanding. His role as a creative and design implementer should be to respect traditions, religion and to use materials of a reasonable cost.
3. Almurahhem (2008) uses Jean Nouvel's Arab World Institute concept as an example to show that modern technology and traditional architecture can successfully combine for the benefits of occupants without the need to disregard Arab cultural heritage.
4. Ghiasvand (2008) and Moradi (2008) argue that there is a need to appreciate, understand and evaluate the architectural quality of traditional buildings. They envisage a need to develop a sense of dimension, climate, topography, materials, physical natural and human-made environment as well as proportions to go beyond utilitarian needs. They highlight the fact that rapid growth in Gulf countries means that it is time for in-depth architectural research studies or a comprehensive new interpretation of the finest values

of Islamic architecture and its traditions. A real test of Muslim architects' ingenuity, they suggest, is to be able to merge the spirit and beauty of ancient architecture and current technological advances within a modern idiom.

5. Eldemery (2009) addresses decision makers by providing a set of guidelines to be used, which can be operationalised and applied in future local projects. His emphasis is on the importance of the change in living patterns and technological innovations. He also urges architects to think "glocally", a composite term for appreciating the local context in its global position. This is done using traditional consciousness and maturity of future vision.
6. Omar as cited in Sidawi (2012) rejects the "copy-paste" of applying old archetypes to new buildings.
7. Ajaj and Pugnaloni (2014) calls for a serious analysis of the rich architectural heritage context. Consideration should be given to the human, cultural and environmental values of this context. Conscious adaptation and implementation should be integrated in the context of contemporary conditions and technology.

2.2.3 Bahrain as a context of study

This section provides an overview of Bahrain as one of the Arabian Gulf countries. Its economy, population, climate and architecture is representative of the Gulf region. It shares similar Islamic religious beliefs and traditions to its neighbouring GCC countries. The advantages of selecting Bahrain as a case study context include its relatively small size, which is beneficial for extracting and understanding the research constraints, and it is also possible to use the case study of Bahrain to reflect on other GCC countries. Historical evidence and current evidence marks Bahrain as having been at the crossroads of commercial importance for over 4,000 years and it has continued to be so after being the first Gulf state to discover oil in 1932 (Bahrain.com, 2015).

HISTORY AND HERITAGE

Bahrain, which means 'two seas', is a group of small islands located in the Arab/Persian Gulf. This community of individuals originally earned their livelihood from the sea. Ben Hamouche (2004) claims that Bahrain's location played an important role in defining its history, social structures and politics. Ancient civilisations had resided on its land, lending Bahrain its special place in the Gulf region. The ancient Dilmun civilisation meant that Bahrain was a centre of trade, linking the East and West. Thus, Bahrain flourished as a merchants' hub for the rich pearl diving industry and as a centre of Gulf trade routes (Bahrain.com, 2015).

The 16th century marked the arrival of Portuguese people to Bahrain, who started the spice trade in India and the pearl trade in Bahrain. Yarwood (1988) and Dayaratne and Karajica (2011) note significant influences by other Westerners in Bahrain following the British colonisation (1820–1971) and the arrival of Americans, although neither occupied the country. Moreover, they have made remarkable impacts in terms of development and society, social structure, the use of the English language, and planning practices. Another significant influence claimed by Yarwood (2001) and supported by Dayaratne and Karajica (2011) is that of the Iranian/Persian culture across the Gulf countries and in Bahrain in particular. Since 2010, the Bahraini Ministry of Culture (MOC) has been working on documenting Bahraini old cities as world heritage sites (Alkhalifa, 2015). However, the act of sustaining heritage can be divided into two roles,. Kalliopi (2016) explains:

> *"Firstly, 'sustainable heritage' refers to strategies and policies for making heritage sustainable (from a physical, environmental, economic and social perspective). This aspect entails a more **passive** role for heritage as it implies that heritage is subject to change and risks and hence the need to develop strategies for protecting heritage from those changes and risks applies. The second aspect of 'sustainable heritage' implies a more **active** role for heritage, – heritage as a driver for positive change; as a driver for sustainable development."*

Heritage, according to the views of Alkhalifa (2015) and Kalliopi (2016), is not a passive recipient of change and threats but an **active** driver for development that is socially, culturally, environmentally and economically beneficial for society. However, Kalliopi (2016) asserts that it is difficult for all facets of sustainability (social, cultural, environmental, economic, etc.) to co-exist in harmony, but significant examples of such a combination of passive and active roles have already been initiated by the MOC's new sustainable heritage preservation and renovation projects around the cities of Manama and Muhharaq in Bahrain, (see Figure 2-4).

Figure 2-4 Heritage conservation of Abdulla Alzayed journalism heritage house in Muharraq. Source: MOC.

CLIMATE

Bahrain, an archipelago of 33 islands, has an area of about 711 km². The climate in Bahrain and its archipelago of 33 islands falls within the arid and semi-arid zones of the Earth. Elagib (1997) describes the climate as having a mild winter and a very hot and humid summer. Radhi et al. (2009) point out that the annual average temperature of 26.5˚C and the average minimum and maximum temperatures have increased, as stated by Radhi (2008), due to global warming mainly caused by the First Gulf War in 1991, huge construction projects, and CO_2 emissions from burning fossil fuels. The analysis illustrated in Figure 2-5 is provided by the Directorate of Meteorology on Bahrain's climatic elements. Radhi et al. (2009) indicate that Bahrain's overall average temperature is 26.5˚C throughout the year with a monthly average maximum temperature of 41˚C in August and a monthly average minimum temperature of 14.4˚C in January.

The winter season in Bahrain is short and dry, from late December to January, February and sometimes early March. From March to May the weather is mild. Furthermore, the summer season period lasts from the end of May to September. During the summer, the monthly mean temperature is between 30–35˚C. In October and November sunny skies are dominant, with dry conditions and monthly temperatures of between 24˚C and 29˚C. Bahrain is a humid country, with an average monthly level of 62% humidity. Bahrain has winds from a north-easterly direction throughout the year. The wind speed varies throughout the year; from April to December it is considered low, from January to March it is slightly stronger, and in February it reaches a monthly average of 5.2 m/s. Bahrain, like other GCC countries, is exposed to high solar radiation levels, with a monthly average of 585 W/m². Solar radiation is linked to sunshine hours, as Bahrain receives an average of 3,468 hours annually (Radhi et al., 2008, 2009). Bahrain has about 11.3 hours of daily sunshine in June and 7.3 sunshine hours in January.

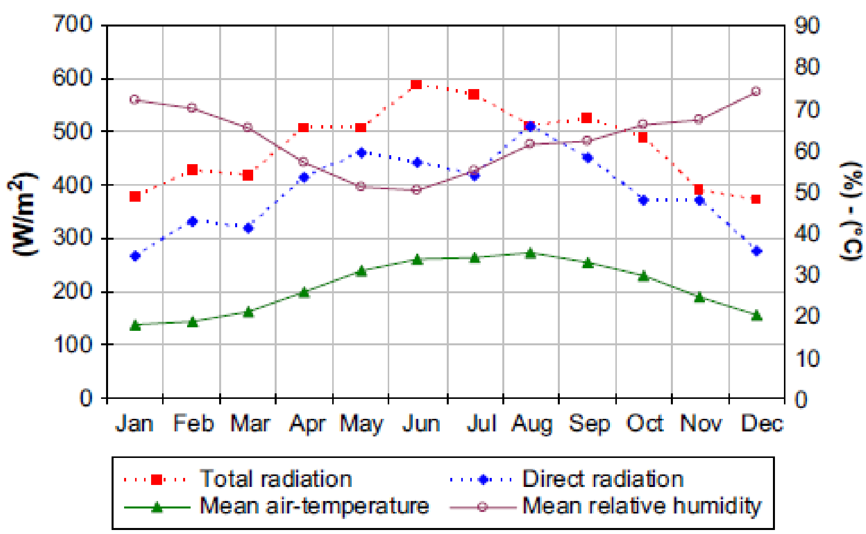


Figure 2-5: Analysis of Bahrain's climate. Source: Radhi (2008).

PEOPLE, CULTURE, RELIGION AND POLITICS

Bahrain's social structure and people are formed mainly of Bahraini Arabs, non-Bahraini Arabs, Persians and Indians, as stated by Yarwood (1988). Recently, the percentages of Arabs to foreigners has accelerated dramatically, due to the economic growth requiring foreign workers. Table 2-2 demonstrates the growth of the total population, which grew from 1.2 million in 2010 to about 1.3 million in 2014 according to the latest statistics published by the Bahraini Central Informatics Organisation (2015).

Table 2-2: Bahraini population from 2010–2014. Source: Central Informatics Organisation Portal (2015).

	Population size per year					
		2010	**2011**	**2012**	**2013**	**2014**
Bahraini	Total	570,687	584,688	599,629	614,830	630,744
	Female	282,235.	288,810	294,275	301,885	309,905
	Male	288,452	295,878	305,354	312,945	320,839
Non-Bahraini	Total	657,856	610,332	609,335	638,361	683,818
	Female	181,951	164,727	154,240	162,925	198,170
	Male	475,905	445,605	455,095	475,436	485,648
Total	Total	**1,228,543**	1,195,020	1,208,964	1,253,191	**1,314,562**
	Female	464,186	453,537	448,515	464,810	508,075
	Male	764,357	741,483	760,449	788,381	806,487

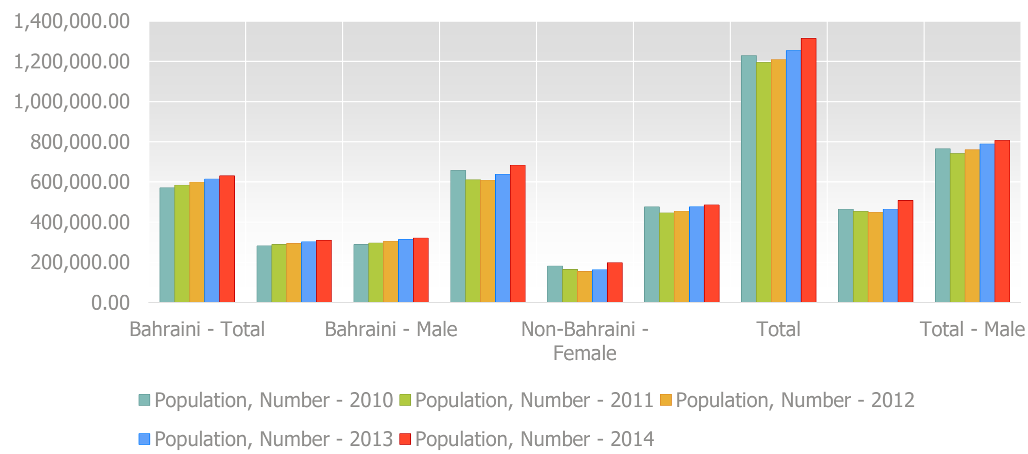


Figure 2-6: Bahraini population. Source: e-government (2015).

Politically, Ben Hamouche (2004) clarifies the location of Bahrain as a strategic point between two Islamic entities: the Arabs and the Persians, the Sunni and the Shi'a, who are regionally known as the powers of Saudi Arabia and Iran. The Persians were expelled in 1783 from the two main islands by the Al-Khalifa family, a successor of the Utob family. The Al Utob Arab tribe then became the ruling family of Bahrain (Fuccaro, as cited by Ben Hamouche, 2004, p. 524). However, after the Persian Revolution in 1979, Yarwood (2001) notes that Persian refugees who flooded into Gulf states like Bahrain influenced it not only socially, but architecturally as well. The most recent political unrest was witnessed in 2011 between the Bahraini Shi'a opposing the government and the ruling family. This has fractured Bahrain's social structure and has affected its economic growth slightly (Kinninmont, 2015).

Socially, it has been documented that Muharraq was the capital of Bahrain until the arrival of the British who developed the town of Manama at the expense of the old town in the 1920s. Religiously speaking, Bahrain is a Muslim country yet it welcomes a mixture of people of different cultures and nationalities, all of whom dress modestly in response to Islamic codes and respected behaviours. Bahrain is also considered one of the most modern countries in the GCC. The discovery of oil in Bahrain in 1932 has impacted the lifestyle and economic status of Bahrain. Dayrante (2012) states that the increase in wealth was followed by international exposure that challenged Bahrain's society and people. This growing island attracted urban migrations, growth in development programmes, mega projects, enhanced transportation systems, modern construction technologies, and an electronic information revolution, thus changing its values and attitudes as a result. Karolak (2010) highlights that by 2008, the expatriate population represented almost half of Bahrain's inhabitants.

Bahrain's culture is derived from the Islamic religion and the environment. The Bedouin desert style was favoured first (Ben Hamouche, 2004). After the arrival of Islam, Bahrain historically embraced its cultural values and identity. Traditions and Islamic values informed one another. Issues of privacy and neighbours' rights were highly respected within traditional architecture (Yarwood, 1988). The domain of women as household wives was the norm during the pearl diving and fishing periods. Althawadi (1974) notes that traditional Bahraini women lived a harsh life. He justifies his claim by stating a few issues that old women had to face, including biased marriage choices, early organised marriages, housekeeping and full home responsibilities during the long months of pearl diving by the men of the family.

It can be concluded that Bahrain's identity and current lifestyle is a composite of three layers. Dayaratne and Karajica (2011) suggest that these layers are an Arab Islamic layer, a socio-behavioural layer and a financial and economic layer. The newest layer is the socio-behavioural layer that is being imposed by the construction of expensive, super luxury living. Exclusive waterfront dwellings and high-rise apartments have informed a new modern lifestyle. Karolak (2010) also supports the argument that the influence of high incomes and globalisation has made embracing a Western lifestyle a new norm. Changes in the consumer culture followed, where Bahrainis were exposed to foreign-branded fashion that promotes the 'status symbols' that the new generation thrives to achieve. Elmesri (2010) opposes this transformation; his argument is built upon the fact that these are fake values which have been reflected in buildings and cities. The local genuine norm which once shaped the culture and its dwellings are missing in new projects, thus causing an 'identity crisis'.

As a result, the English language has overlapped with everyday life, sometimes even being easier to use than speaking Arabic among different groups in the Bahraini society. Karolak (2010) justifies this by outlining two factors. The first is the inadequate proficiency level in Arabic which varies among Bahraini citizens, especially for young children who have foreign nannies. The second factor is that the education system in most private yet bilingual schools and universities around Bahrain embraces English as the main means of communication (Karolak, 2010).

ECONOMY

In relation to the Bahrain economy, Williams (1945, p. 195) as cited by Dayaratne and Karajica (2012, p. 2) writes that:

> *"…even before petroleum outranked piracy and pearls as a source of riches, Bahrein [original spelling] was credited with the highest per capita income on earth"*.

After the invention of Japanese artificial pearls, the pearl industry in Bahrain collapsed. Although the boat building craft was evident, Dayaratne (2008) suggests that it was not enough. The discovery of oil in Bahrain in 1932, the first among other GCC countries, and the economic prosperity which followed, brought many changes to the lives of Bahraini people and impacted the design of their dwellings. Later, compared to other GCC oil countries, Dayaratne and Karajica (2011) state that Bahrain's economy was smaller in size and slower in its development, due to its smaller oil resource base, population and unarticulated aspirations.

Following its first shipment of oil in 1936, Bahrain's oil economy benefitted from 300 oil wells drilled over the following years. In 1942, the banking sector started in Manama, coupled with a commercial centre and the development of infrastructure. The role of Mina Salman as a free transit area became more evident in commerce in later years. Furthermore, Bahrain's international airport was built originally in 1927 and took on new routes and flights in 1934, 1936 and 1970. This resulted in making Bahrain a transit area between major business cities such as London, Singapore, Karachi and Hong Kong (Bahrainport.com, 2015).

In recent years, Bahrain has begun a fast development phase. Several architectural projects started exploding around the island and its new reclaimed lands, such as the Bahrain Financial Harbour. Moreover, it is claimed by Dayaratne and Karajica (2011) that architecture abandoned wind towers and Mashrabiya in favour of central plants and split air conditioning systems. Heritage.org (2015) ranks Bahrain the 18^{th} freest economic country worldwide in its 2015 index. It is ranked after Germany and the Netherlands and before Finland; Bahrain's economic freedom score is 73.4.

The overall Bahraini lifestyle changed after the introduction of relatively higher incomes. Evidence for this can be seen in the transportation shift from horseback to Lexus cars and even in fashion, as argued by Knox (2012). Ben Hamouche (2004) also notes that the huge financial resources as well as the political system allowed governments to adopt a welfare policy. Such policies kept raising the living standards of locals as a major concern and a priority. Nevertheless, Bahrain also concentrated on developing its infrastructure, financial sector, banking and communications as well as commerce and tourism.

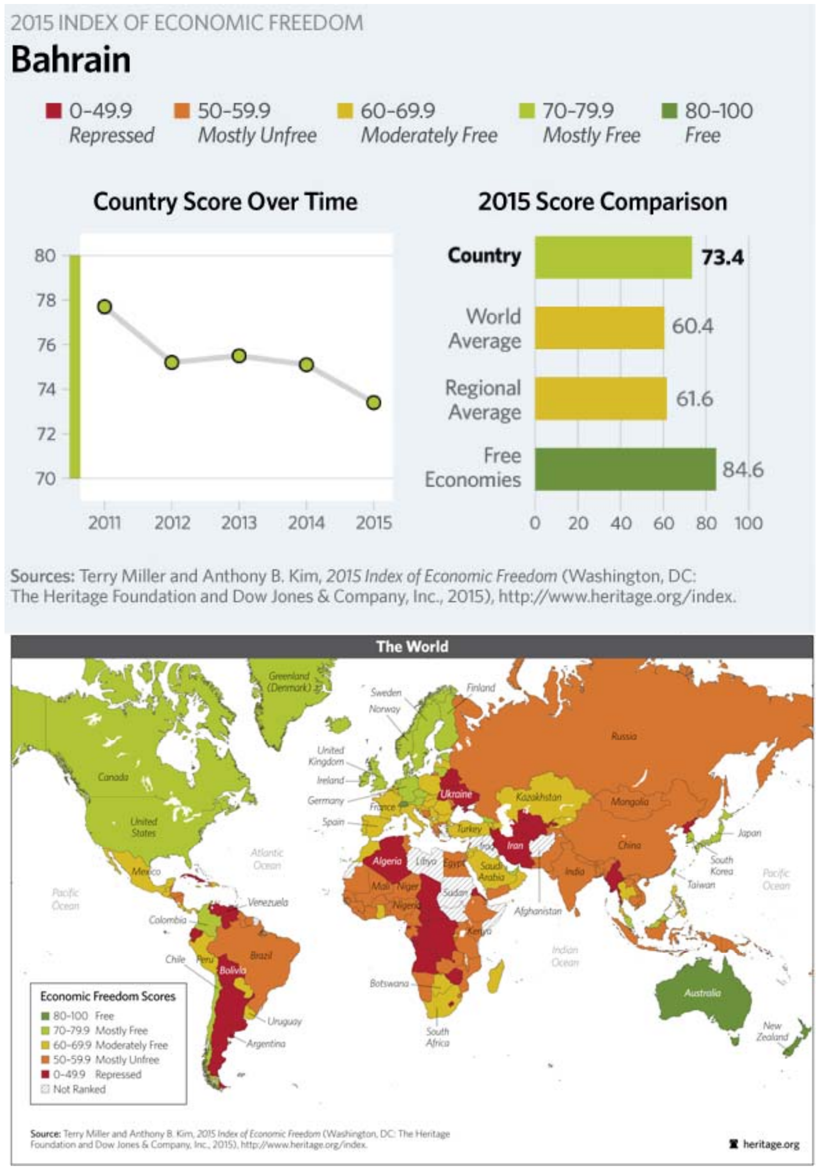


Figure 2-7: Bahrain's position within the world; it is mostly a free economic country. Source: Heritage.org (2015)

The accelerated pace of economic growth in infrastructure and development projects, as well as the shortage of skills from local labour, generated the need for more 'cheap wage' migrant workers (Dito, 2007). English-speaking foreigners and expats and their multiple skills and cultures have definitely affected the market, as proven by Dito (2007) and Heritage.org (2015). Dayaratne and Karajica (2011) also highlight that the construction industry has not just imported labour but has also imported global skills and crafts as well as habits and practices. On the other hand, Bahraini workers' conditions were affected by low wages, as researched by Karolak (2010), resulting in them avoiding employment in the public sector. Consequently, this has led to an increase in the unemployment level among the Bahraini native population. The Bahrain government and the Ministry of Labour and Social Affairs initiated several policies to develop Bahrainis' employment skills and involve them in the market.

The recent and most promising aspiration is considered to be the Bahrain economic vision 2030. The government aspires to shift from an oil-based economy to a globally competitive one (Ministry of Industry and Commerce.gov, 2015). The vision aims for a range of middle-class Bahrainis to enjoy good standards of living through an increase in income and productivity. This involves embracing principles of sustainability and fair competition. This vision has a strong influence on the argument of this research. Ahmadi (2014) considers the 2030 initiatives that followed as a vital support for the entrepreneurship programmes promoted by EDIP and developed by the UNIDO group. The role of the Economic Development Board (EDB) is also very important and is further discussed by Wright (2010).

In order to achieve the goals of the 2030 vision, financial support for individuals was initiated. Tamkeen is a body known for supporting start-ups and entrepreneurs. The Tamkeen incubator provides workspaces for a very low rent. Moreover, there are subsidies of 80%, up to BD 15,000 (£26,630) for each programme's technical equipment, marketing and exhibition participation. Ahmadi (2014, p. 37) calculates these benefits as "… a grant of BD 12,000 (£21,304) for equipment, BD 3,016 (£5,354) for exhibition participation, and BD 1,508 (£2,677) for advertising. A total amount of BD 16,524 (£29,336), which is equivalent to 15.5% of the initial investment budget".

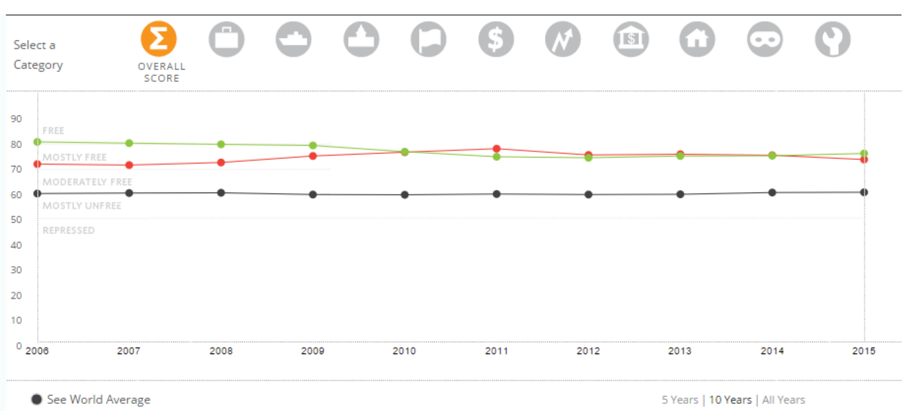


Figure 2-8: A comparison of overall economic scores for Bahrain (red) and the UK (green) and the world average (black). Graph generated by Author using data generation from: http://www.heritage.org/index/

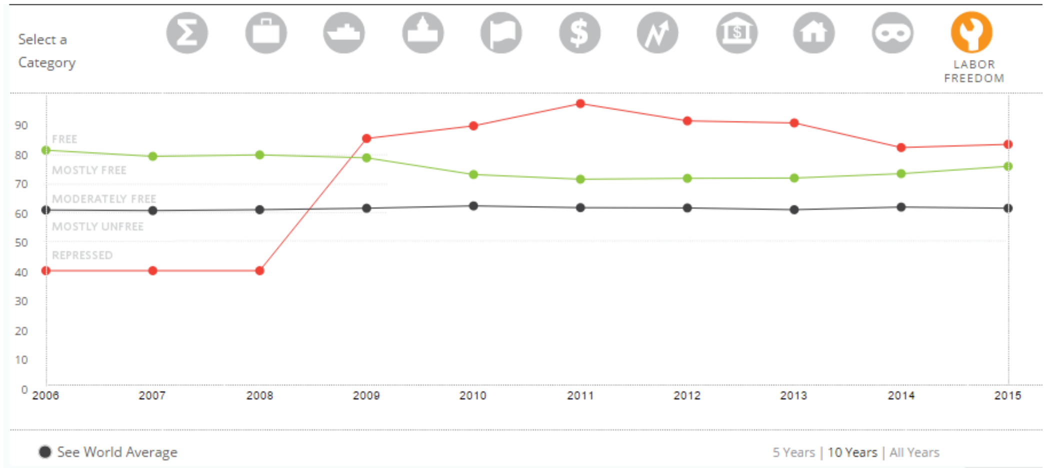


Figure 2-9: A comparison between labour freedom in Bahrain (red) and the UK (green) and the world average (black). Graph generated by Author using data generation from: http://www.heritage.org/index/visualize

CHANGE IN SOCIO-ECONOMIC SCALE

An important angle from which to view the Bahrain economy is the emergence of the "consumerism culture" (Karolak, 2010). Using their increased individual income, Bahrainis favour foreign and branded products and goods (Assad, as cited by Karolak, 2010). Western luxury brands are favoured. Karolak (2010) supports Ben Hamouche (2004) and shows how public surplus revenue resulted in an increase in the purchase of imported consumer goods such as household goods and electronics as well as imported furniture. The influence of globalisation and Westernisation following Bahrain's independence has extended the development of global mass consumerism (Turner, as cited by Karolak, 2010). As noted by Ibrahim (1992) as cited by Karolak (2010), the results of these new modes of consumption have contradicted the traditional culture of Bahrain. Therefore, it can be concluded that the socio-economic scale of Bahrain has shifted towards a mixture of local cultures: "mass universalism" (Turner, as cited in Karolak, 2010.)

ECONOMIC FACTORS AFFECTING ARCHITECTURAL DEVELOPMENT

Bahrain's economy, as developed as optimists would like it to be, faces several dilemmas. Elmasri (2010) highlights these dilemmas as being related to a lack of local expertise, the huge number of foreign experts and labour, and a misunderstanding of the value and potentials of traditional architecture. The former can lead to the disappearance and deterioration of traditional settlements. Radhi (2013) looked into the economic and social transformation and the rise in employment as an extra CO_2-emitting dilemma. However, from an environmental point of view, Bahrain has a lower carbon footprint than its neighbouring GCC countries. This is due to the absence of heavy factories and huge industrial plants around the island. As a result, a total dependency on imported goods and foreign workers is evident.

Karolak (2010) gives an opposite optimistic view towards Bahrain's economy by suggesting that the modernisation and globalisation of Bahrain can provide a better economy. Her argument supports the notion that urbanisation stimulation, marketisation and industrialisation can highly benefit the economy and that the obstacles mentioned earlier by Elmasri (2010) can be consciously overcome.

The manufacturing market has also been affected by the shift in the built environment. Four famous crafts were noteworthy locally: the metalwork of window grilles, timber wood fretwork used in window screens and ceilings, door and shutter wood carving, fanlight stained glass and plaster carving (Yarwood, 1988). Bahrain's old craftsmanship in pottery and boat making could not survive modernisation, regardless of their influence on the architecture of Bahrain (Dayrante, 2008). Also, Ben Hamouche (2004) argues that the growth of the service sector is causing traditional crafts, artefacts and markets to collapse. From craft to construction, Alaali (2006) gives evidence of the change into a new construction industry that offers imported concrete and aggregate to replace traditional material resources like limestone. This can be an acceptable result; as Samuels (2011) suggests, the industrial revolution followed by huge economic changes made it financially impossible for traditional craft-based architecture to survive.

From architectural manufacturing aspects to design and prototyping solutions, CAD modelling knowledge is acquired by university graduates and designers in Bahrain. Yet digital fabrication is not well established. Ahmadi's (2014) investigation into the Bahraini new manufacturing market confirms the minor use of digital fabrication using CAD and CAM tools. However, there is a gap in knowledge when it comes to the advanced application of digital fabrication in architecture, as it is still at a stage of infancy. One supplier of 3D printers (KBProto shop) and a few jewellery designers are relying on digital craftsmen for the use of 3D printing in their small-scale designs. However, architecture firms mostly rely on foreign craftsmen with CAD and 3ds Max rendering skills. Therefore, it can be argued that the quality of the digital craftsmen versus that of manual craftsmen is highly dependent on foreign workers' previously acquired skills and not that of a Bahraini market demand. Increasing knowledge, awareness and educational programmes and the Fab Labs studio in Bahrain, as suggested by Ahmadi (2014), can be a way to bridge the gap between the architecture and manufacturing markets in Bahrain.

ARCHITECTURAL FEATURES OF BAHRAINI HOUSES

The architectural features of Bahraini houses are similar to those of the earlier discussed Gulf houses presented in Table 2-1. Again, culture, tradition, religion and the environmental hot and humid conditions governed aspects of building construction. The common architectural features have changed due to economic growth and industrialisation, as discussed in the previous part of the research.

Although extensive research has been carried out on Bahraini traditional and modern architecture, no single study has shown the effect of socio-economic conditions on architectural products in the 21st century in Bahrain. The work of Yarwood (1988), Wally (1993), Fuccaro (2001), Elmesri (2010), Ben Hamouche (2004), Dayaratne and Karajica (2007), Dayaratne (2008) and Aljawder (2014) are scholarly examples of either social or architectural and urban development research focusing on Bahrain.

Table 2-3 describes briefly the phases that Bahraini architecture has gone through, as researched by Elmesri and Alraouf (2006) as cited by Elmesri (2010), with the author's interpretation. The author grouped aspects of change into themes derived from the literature. Important factors that determine development are culture and politics; social, aesthetic, functional as well as economic factors are documented here to give a better understanding of the current and possible future architecture of Bahraini houses.

The facade treatments reflect the unique architectural language of society. Windows in particular are a mediated interface between the outer functional world and the intimate social interior space. Window shading and Mashrabiya are a reflection of most of the issues discussed above and represent a key factor in the architecture of the veil. Therefore, the traditional window shading known as Mashrabiya will be discussed next in section 2.3.

Table 2-3: Major aspects affecting architectural facades in Bahrain. Source: Elmesri and Alraouf (2006), modified by Author with reference to the literature.

Era	Stage	Form	Social aspects	Aesthetic aspects	Functional aspects	Economic aspects
Late 19th C. to 1930s	Pearl Diving	Form Follows Family	-Culture originated from Islamic values and principles. -Family and community-driven urban forms. -Hybridised with other Arab, Asian and African qualities.	- District-based dense organic urban fabric. -Simple forms and decoration. -Privacy in design is of major importance. -Local materials used: gypsum, limestone.	-Construction system responded to culture and environment. -Courtyard house characterised by ventilation techniques, bent entrance, and usage of flexible rooms.	-Life depended on agriculture, fishing, pearling and trading.
From 1930s to 1960s	After Oil Discovery	Form Follows Function	-Confusion of the value of traditional areas as opposed to modern housing projects. -Nuclear families wanted separate houses.	-Construction focused on infrastructures. -Gradual destruction of traditional areas. -Desertion of locals to modern housing areas. -Foreign labour rent traditional old houses.	-Uncoordinated building activities and lack of comprehensive conservation strategy.	-Shift from agriculture and pearl diving-based economy to oil-based economy. -Massive foreign labour influx and introduction of 'modern' town planning supported by British colonial power, and the pursuit of the modernisation process.
From 1960s to 1990s	Independence		-Further deterioration of traditional areas. - Social bonding still important. -The effect of Islamic values on privacy was redundant for a while. - Women started employment and education.	-Palladian villas competing with Oriental style. -Preference for Western courtier designs seen by locals when visiting the West.	- Modernisation and population growth affected urbanisation. -Massive government social projects economically affected by Western model of planning.	-Growing economy yet it slows down during the Gulf War.
Since 1990s	Globalisation	Form Follows Finance/Fashion	-Social bonding did not **regulate** houses. -The importance of visual privacy associated with curtains and double glazing.	-Development projects of modern and functional style, compact houses and **high** aesthetic value.	-Massive urban development projects with various scales, styles and costs.	-Government involvement in urban projects in real estate and land market. -Urban developments characterised as **starting slowly** from 1990 to 2000, then accelerating and intensifying between 2006 and 2008. -Construction market strongly affected by the late 2008 economic crisis. -Cancelling, resizing, phasing or re-evaluating became a common trend after the financial crisis.

Housing built at this time may be claimed to constitute a balance between the inhabitant himself as an owner and between his personal dwellings and the general city (Wally, 1993). The most dominant feature of this era was the inward orientation of dwellings. Courtyard houses were the norm for middle and high-class Bahrainis, while fishermen's huts named Parasti used palm tree leaves as a local cheap construction material. Both considered windows an important element but the windows were of a small scale. Ensuring privacy through these windows was a must. Using simple upward louvres, Mashrabiya or palm leaves were popular. Few old houses in Manama and Muharraq still exist to provide evidence of this era (Dayaratne and Karajica, 2011). Figure 2-10 shows a Bahraini hotel with its ornamental closed balcony and side Mashrabiya. Many palm houses were located by the sea due to pearl diving and fishing.

The oil period was a transformational one for Bahrain both in terms of building architecture and its economy as explained in Table 2-3. The Ministry of Culture (MOC) role in preserving the local identity is accelerating. MOC regeneration of the capital Manama market with enhanced activities and shopping experiences to bring locals back to it is an important step and example towards preserving identity and heritage of such vital city as seen in Figure 2-10 and Figure 2-11.

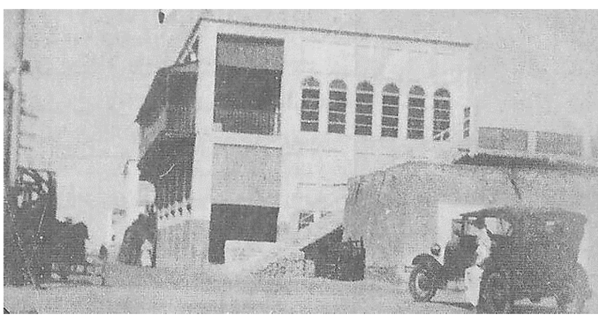



Figure 2-10: Bahrain in the 1930s. Source: Gulf Insider (2015).


Figure 2-11 Bahrain market gate and the architecture transformation from the 1970s to 2010. Source: http://www.e-architect.co.uk/images/jpgs/bahrain/bab_al_bahrain_1950_m171111.jpg

SOCIO-CLIMATIC ENVIRONMENT OF THE BAHRAINI HOUSE

SOCIAL OBLIGATION AND RESPONSES

Social structures and the transformation of the Bahraini society have been significantly affected by the economic growth resulting from the oil industry. As Elshorbaji (2010) comments, courtyard houses and Mashrabiya no longer represent the functions of peace and modesty. The complex family structure that contained multiple generations all living in one courtyard house has reduced. The activities performed in the previous courtyards have been terminated in modern housing, as discussed by Khalifa (2011). The reduction in available building land and the extreme jump in land prices forced Bahraini house designers and project developers to design more compact houses. With dwellings being built adjacent to each other or stacked in multi-storey buildings, issues of privacy and passive environmental control have become reduced to a minor concern.

Hui (2005) claims that vernacular courtyard houses had once enhanced the feeling of community and belonging. They were a direct reflection of people's experience of a place and regenerated and sustained local economics. He rejects the unthoughtful new architecture as causing alienation and socio-cultural displacement. Alaali (2006) supports Hui (2005) and explains that modern housing is just a reflection of the current Bahraini situation. This means that it is a complex of contradictions between a set of political, religious and economic values. These contradictions have strongly affected the island's architecture.

Sustainable socio-cultural based housing is what current scholars like Abdelsalam and Rihan (2013) and Hui (2005) are calling for. These housing types can be defined as ones that are designed by the government to balance local users' needs and their cultural as well as social needs. However, the current housing trend and development projects have not always been successful in addressing these issues. Evidence presented by Dayaratne and Karajica (2007) about such projected identities reflects the fact that new concepts are not socially driven anymore. Therefore, new houses in Bahrain can be claimed to not always be as socially responsive as they are argued to be, and this was evident in Khalifa's (2011) study results as well.

CLIMATIC PROBLEMS AND RESPONSES

Bahrain's hot climate forces more energy to be spent on cooling buildings. Alnaser (2011) and Radhi et al. (2009) indicate that the domestic sector consumes 54% of the total energy. They claim that most of this energy is being consumed by air conditioning systems to cool poorly designed dwellings.

When Bahrain began outlining building standards for energy efficiency in 1998, there was a need to build with the climate in mind and with a sense of place. Unfortunately, Radhi et al. (2009) indicate that the design of building parameters has not yet been perfected in new dwellings compared to traditional ones. A lack of understanding of thermal performance can be an issue. The importance of energy savings in new houses could equal $600 billion annually by 2020, as indicated by Minister Alkhalifa's speech.

Building designs are likewise important for window design. Solar radiation is a serious concern; therefore, glazing should improve the solar performance. Radhi et al. (2009) advise that window areas should be reduced. The shading coefficient, light absorption and reflection should also be considered. They strongly recommend the use of shading devices when possible.

Sustainable materials and massive construction, the orientation of buildings, narrow passages and streets, multi-storey buildings, roofs and terraces, courtyards, openings and Mashrabiya can be considered as responsive products to such an environment.

BRIEF REVIEW OF NEW HOUSES IN BAHRAIN

TRADITIONAL/ORIENTAL HOUSES

The traditional houses in Bahrain are representative of the architectural layout of other Islamic countries that based their architecture on courtyard openings, as noted by Kazerooni (2002). This type of dwelling is formed of one master or more central courtyards surrounded by built areas. Thus, this allows inward orientation and privacy to be secured at all times. The form and room types as well as passages and decorative treatments have been discussed intensively by several scholars such as Yarwood (2005), Kazerooni (2002) and Ragette (2012). The uniqueness of this traditional type of architecture has remained as a memory of Bahrain's architectural identity. Fine gypsum work, sea stone and imported wood were the main materials used in courtyard houses. Another unique characteristic of such a type of architecture is that the houses were built by the master builder and the owner gave their ideas on site which, as Kazerooni (2002) highlights, resulted in a true representation of the family's needs and culture. This argument is also supported by Khalifa's (2009) study about the social changes in family structure and strength that differentiate courtyard houses from the new houses.

Traditional courtyard houses ranged from small one courtyard houses to multiple courtyards in royal family houses. Scholars assures that houses of this type stand as proof of their success in achieving the socio-climatic needs of the Bahraini culture before the oil discovery, (Alkhalifa, 2015 and Dayaratne and Karajica, 2007). Nevertheless, it can be argued that traditional houses remain until today as an image of a past identity that current project developers or social housing architects tend to replicate superficially in their designs. The disadvantage of this superficial replication is the use of the shape of a once functional courtyard product like Mashrabiya and wind towers and not the function they served, as researched by Dayaratne and Karajica (2007).

The simplicity of the courtyard house exterior put an emphasis on its openings as sources of decorative treatment. Yet, corresponding to Islamic religious values, Old Bahrainis avoided spending money on lavish exterior decoration and favoured interior inward ones. Mashrabiya screens, however, used to be one of the elements used to soften the solid mass look of the house's exterior.

PRIVATE HOUSES AND VILLAS

It can be claimed that private houses and villas gained popularity after the increasing income resulting from oil wealth and the transformation in family type from an extended to a nuclear one. Ameen (1983) links the changes in the nature of Bahrainis' family size from extended to nuclear with the spread of families among new housing types offered by the government. The Bahraini government new development projects and social housing blocks catered for this change in the family size. Dayaratne and Karajica (2007) further explain the tendency of new Bahraini families to build new villas of a Palladian architectural style, claiming them to be inspired by the Western cities Bahrainis often travelled to. The imported Palladian-style architecture also shows use of symmetry of forms, pediments, domes, porticos and balconies that may not be suitable for Bahrain's environment and social values.

The past 10 years have also witnessed the widespread of new modular villas, smaller in size due to high land prices. Their design tendencies reflect a modern and contemporary architectural style, where most are either influenced by a copy-paste design strategy from Western architecture, as claimed by Sidawi (2012), or integrate environmental and economic values and new forms. Ranging between three to five bedrooms with an introduction of mixed gender living and guest spaces, a new social and cultural shift has been detected by Dayaratne and Karajica (2007).

RESIDENTIAL FLATS

Land prices have grown significantly, almost trebling in the last 10 years. This can explain why there has been a call for more residential flats to be built. Social housing has been widely replaced by housing flats. High towers dominate Bahrain's skyline and issues of parking and privacy in connection with these flats and their neighbouring buildings or houses has been a growing dilemma in the past five years.

SOCIAL HOUSING

The Bahraini Ministry of Housing, since its establishment in 1975, has been concerned with providing decent housing for all low-income Bahrainis (Ministry of Housing, 2015). Ranging from housing units or flats to housing loans and land, the Ministry's vision is to ensure superior quality and sustainable living dwellings for Bahrainis. Many of the housing units built by the Ministry reflect a blend of traditional style architecture with a modern form that fits today's lifestyle. With three to four relatively small rooms and repetitive units, the majority of social housing can be argued to lack customisation for individual needs, as can be seen in Figure 2-12. This is due to the fact that the modular repetitive social housing design does not reflect the user needs or style of preference.

Figure 2-12: Social housing in Bahrain; Mashrabiya resemblance in facade. Source: Author 2014.

DEVELOPMENT PROJECTS, HOUSES AND FLATS

According to an estimation by Meed Projects, the market for development projects in Bahrain is valued at about $65 billion, as indicated by tradearabia.com (2015). Construction of new development projects and housing plots is valued at $30.4 billion. The previous and current housing projects cannot be ignored in this research, as their design and facades are of high importance and influence. The form, lifestyle and design of rooms and windows are shaping a new architectural style based on economics and aesthetics as well as material efficiency. Dayaratne and Karajica (2007) claim that super luxury living through these new development projects can be viewed as a new layer of Bahraini identity. The new developments target rich and wealthy residents from Bahrain and the Gulf, containing private beaches and suburb landscapes and facilities. Figure 2-13 shows the application of wooden Mashrabiya as a window treatment in one of the major development projects called Amwaj Islands.

The designers' desire to revive a traditional look by implementing wooden Mashrabiya can be considered as a wrong decision. The untreated window wood screens could not stand the humidity of the nearby sea and lost their aesthetic beauty within two years after the project's completion.

Figure 2-13 Amwaj Islands Mashrabiya. Source: Author.

INFLUENCE OF TRADITIONAL ARCHITECTURE: CONSCIOUS AND UNCONSCIOUS APPLICATIONS

Some of the local and the foreign architects in Bahrain were noted to have a limited design vocabulary to work with while designing new houses. Many houses can be thought of as a replica of either traditional houses or Western houses. By replicating traditional houses, some designers and architects relied on the decorative elements and the superficial forms of Bahraini heritage like the Badgir and arches. Unconscious application of traditional architecture appeared in the facade treatments of several projects. Dayaratne and Karajica (2007) also indicate that a new Bahraini identity was created by the blend of historical narratives with luxury living and prestigious leisure spaces that is reflected in the facades of the dwellings.

According to Alaali (2006), houses in Bahrain are today being built in the centre of the land, surrounded by a yard. According to the building regulations in Bahrain, houses are set back almost 2 metres from the perimeter fence. This has caused intrusions into women's privacy within the house's outdoor space. Other unconscious applications of traditional architecture include the concealing of cross ventilation through rooms and denying women the ability to open windows at night due to wanting to protect them from being seen.

WINDOW TREATMENTS OF CURRENT BAHRAINI HOUSES

Window size and treatments in Bahrain have been related directly to their environment and the building aesthetics. Cultural constraints can be seen as being less influential on the exterior treatments of the windows, as double glazed windows are mostly used (Alaali, 2006). However, with regard to the interior, all windows in dwellings are treated to ensure privacy at night when double glazed windows display the activities of those inside.

In Bahrain the treatment of window glass can slightly differ from one house to another. However, aluminium framing is the most popular choice nowadays, due to its durability. Wooden window treatments are expensive, as shown by Aljawder (2014). If wooden designs are used in a Mashrabiya product to cover windows, it would preferably be made from solid wood to withstand high humidity and temperatures. GRC ornamental screens were used in social housing projects to revive the traditional look of the old gypsum treatments but are not seen today in modern houses. A new trend of using CNC wood screens from MDF is gaining popularity according to a designer in one of Bahrain's wood factories. However, CNC screens are recommended to be used inside the house instead of on the exterior facade.

BUILDING CODES AND REGULATION OF WINDOW TREATMENTS IN BAHRAINI HOUSES

The government of Bahrain does not have any regulations regarding window treatments during the design stage, it only requires it to function as a natural ventilation source. However, window specifications in general are outlined and classified and further discussed by Radhi (2008). Shading devices, however, are preferred to be openable in upper floors; this is to allow easy access to the apartment or house during firefighting. This rule is the only one that is valid for shading devices. However, many locals and project developers do not include shading device designs, drawing initial approval from the fire defence department. Most are added elements and accessories to the building, added in a later construction phase.

2.3 THE MASHRABIYA

2.3.1 Definition: From regional to local

The Mashrabiya can be historically traced to the Mamluk and Ottoman periods in Egypt (1517 ~ 1905) (Abdelgelil, 2006). Since then, several culturally made Mashrabiya have existed according to their particular context and region. Several definitions discussed here are related to the meaning, functions and regional characteristics of the Mashrabiya. A Mashrabiya is defined by the Oxford Dictionary of Architecture (Curl and Wilson, 2015) as a timber "lattice screen", often intricate, geometric and beautiful in Islamic architecture. Different spellings such as *mashrabiyya*, *meshrebeeya*, *mushrabeyeh and mouchrabieh* are common in the literature as the term was originally translated from the Arabic language. The word Mashrabiya is argued to be derived from the Arabic verb *shareba*, which means 'to drink' (Kenzari and Elsheshtawy 2003; Elshorbaji 2010). This is due to the fact that water jars used to be placed inside Mashrabiya inner shelves to be cooled passively. Another word that can accompany Mashrabiya is *Mashrafiya*, derived from the Arabic word *Sharefa*, which relates to the opening's high position and the fact that it overlooks lower spaces and passers-by (Almurahhem, 2008; Aljawder, 2014).

The form is also argued to overlap with another archetype known as *Rawashen* in the Hedjazi houses of Saudi Arabia (Almurahhem, 2008) or *Shanasheel* in Iran and Iraq. It is also thought to be linked to the Ottoman Empire's Heremlik window grille termed *Kafe* (Sedky, 1999). The term usually describes a bay-protected or projected closed balcony with small openings so that the female inside the house can look outside without being seen from the outside. As Sidawi (2012) clarifies, such an unveiling may violate the Islamic rule concerning the virtue of women's privacy, and the veil (head and body cover) should remain covering the head and body from non-kinsmen. Outside the Middle East, Hui (2005) argues that architectural treatments such as the *Brise Soleil* and *Claustrum* can also be linked to the Mashrabiya's function and role within a facade.

There is some contradiction over the origins of the noun "Mashrabiya". Kenzari and Alsheshtawi (2003) state that the word Mashrabiya is derived from the Arabic verb *shariba* ('drinking') as the window contained a niche in which pots and jars of water were stored for drinking. A descriptive definition of Mashrabiya is put forward by Samuels (2011), who states that it is a carved wooden screen that lets in ambient light yet restricts direct light. Size-wise it can cover wide openings on the side facade of the building without causing a boost in the interior temperature. Thus, it results in a steady airflow and ensures rooms remain cool yet light, breezy and comfortable. Additionally, Mashrabiya provide privacy to the occupants, an important factor in the predominantly Islamic countries of the Middle East. In relation to its form, Samuels (2011) merits the Mashrabiya with an artistic character, which derives its architectural expression from desert houses. However, he argues that their current uses rely on their beauty, regardless of their visual and functional merits.

Abdelgelil (2006) exemplifies the typical Mashrabiya form found in the Egyptian context. It is made of unvarnished wood, either flushed with an external wall or extending out from the wall:

> "the main Mashrabiya opening is composed of a lower part below eye level with fine-tuned pieces in a tight lattice pattern and an upper part above eye level with a more open lattice pattern and an upper part above eye level with a more open lattice pattern of turned wood, the second part consists of an overhang found above the main Mashrabiya opening. Thirdly a flat grilled window above the overhang that was often added if the Mashrabiya didn't provide sufficient airflow" (Abdelgelil, 2006, p. 2).

One of the most influential figures in the field of vernacular architecture is Hassan Fathy (1986), writer of the famous book "Architecture for the Poor"; he defined the Mashrabiya based on its five functions. It is used as a device to control the passage of light, to control the airflow, to reduce the temperature of the air current as well as to raise the humidity of the air current leaving the building. Lastly, according to Almurahhem (2011) it is used to ensure privacy between the exterior and interior, or within the Salamlik (men's quarter) and the Haramlik (women's quarter) in the courtyard houses of Egypt, Turkey, and other Eastern countries.

The five functional roles of Mashrabiya as defined by Fathy (1986) are the most essential ones. Environmentally speaking, Ficarelli (2009) explains how the window elements automatically activate a convective cycle that is capable of moving air masses from a higher pressure zone to that of a lower pressure. Socially, the role of Mashrabiya was that of a product of gender segregation, home seclusion and a veiling norm regulator. Nevertheless, it also mediated between architectural and interior experiences, allowing female occupants to observe exterior life without being observed themselves. Almurahhem (2008) adds another perspective by unleashing a poetic picture of the space behind the screen. She visualises it to be a sensory experience provoker, where women do not just socialise and gossip with other neighbouring women but may also use it to hear their children play outside, and call for road merchants to buy daily used items.

"*Transparency without a glazed medium*" is how Kenzari and Elsheshtawy (2003, p. 17) link the form of the Mashrabiya to an architectural veil, similar to Muslim women's body and head textile veil. Thus, Mashrabiya can have a social, political and mystical form. Kenzari and Elsheshtawy (2003) consider the technique of executing holes and perforations in the solid wood as a necessary step to "reach the goal of stepping beyond the materiality of the screen".

A complementary theme is the relation between Mashrabiya and light. In Muslim culture, Alsarf (2012) explains how light is a "*symbol of divine unity*", while Aljawder (2014) supports this view through her research of the relationship between daylight and visual privacy. Both scholars and others agree that the Mashrabiya enables the passage of divine light that modifies other elements and originates patterns. Ghasvand (2008) suggests that with the right light going through the pierced screen, the facade can resemble lace. Light and shadow also add dynamic rhythm to architecture and its forms, giving texture to smooth surfaces. However, summer light can be harsh and cause severe temperature rises in the interior. Mashrabiya screens fulfil this cultural need by responding and blocking direct light and reducing solar gain, as noted by Samuels (2011) and Aljawder (2014).

Furthermore, Mashrabiya craft emerged in relation to panelling that was stimulated in Egypt for both social and environmental purposes (Fathy, 1986; Alshareef, 2001; Kenzari and Alshestawi, 2003; Abdelgelil, 2006). The fine techniques of turned wood produced lattice-like panels and sun screens. The screen construction used fine wood since good wood was scarce and highly priced. The basic principle of Mashrabiya is simple, being a lattice constructed of turned oval shapes joined and composed together by short turned and ribbed links (Williams, 2008).

Fathy's experimentation led to him discovering that different sizes of the interstices (spaces between adjacent balusters) and the diameter of the balusters would affect different functions. For example, a Mashrabiya with small interstices is suitable for intercepting the direct light and reducing glare, while Mashrabiya with large interstices will let in indirect light. In addition, the size of the Mashrabiya is also connected with its social function: the feeling of privacy. Mashrabiya with small interstices will provide privacy from outside for the inhabitant, at the same time without blocking the view from inside. The material of the Mashrabiya is also important as it is closely connected to its humidifying and cooling functions.

In terms of materials, Fathy affirms that all organic fibres, such as wood, absorb, retain and release considerable quantities of water. This evaporative cooling phenomenon appears when wind passes through the interstices of the wooden Mashrabiya; the water in the wood will be heated and released, so that the air is cooled and humidified. Eventually, every minor change in the Mashrabiya size and material should be conscious, otherwise the related performance will be impacted. (Fathy, cited in Hui, 2005).

A wider definition of Mashrabiya can be linked to similar products of Mashrabiya seen around the region. All of the facts stated above are to a certain extent an Oriental perspective towards the Mashrabiya. However, from Westerners' perspective, John Fenny (1974) poetically verifies the relationship of the Mashrabiya to magical experiences. He describes the screens as silken masks of the facade, and a symbol of "*the legendary mystery of the Orient*". From his standpoint, Mashrabiya in modern Cairo have become comfortable havens used by the occupants to recline in thermally comfortable and private spaces while observing the streets or courtyards below. Most of these occupants are ladies within their quarters who enjoy the fact that they can see or hear the visitors without being seen themselves, as part of their veiling. Lautrette (2006), as cited by Alanazy (2007), sees Mashrabiya as essential elements in Kuwait (one of the GCC countries) that respond to the notions of privacy and security within the Kuwaiti community, besides their role as ventilators. To Western architects, the Mashrabiya is much like the Oriel and bay window building elements except for its feminine characteristic.

2.3.2 Mashrabiya and other related common names

It is claimed that there is no clear indication in the literature as to the original use of Mashrabiya (Kenzari, 2003). However, the term was associated with lattice screens in Egypt. Different regions have named it descriptively in relation to their languages. In Yemen it is called *takrima* (meaning full of holes), in Algeria it is associated with Turkish architecture and named *gublae*, while in Tunis it is *barmalqi*. In Iraq the device is named *shanashel* (Kazerooni, 2002), and in Iran it is called *mushabak*. In Jeddah and Mekkah, Saudi Arabia, Mashrabiya are named *rawashin* (Almurahhem, 2009). There are similarities to other countries' devices, like those of Japan, where Abdelgelil (2006) relates the traditional fixed Mashrabiya to *machiya-goshi* that allows for complete openness. In 2010, Almurahhem published an article that relates the *rawashin* of Jeddah to the Indian jail screen. It is also hinted by Kenzari (2003) and Hui (2005) that modernists, such as Le Coubusier who was in favour of using the brise soleil as a climate-modifying element, may have been influenced by the Mashrabiya.

The devices listed above, along with many other shading devices of environmental value, have been developing rapidly. Buildings have been developed that take into consideration the context of the built environment, surrounding materials and inner social needs as well as cultural values and privacy levels (Ben Hamouche, 2004).

2.3.3 Historical background

Abdelgelil (2006) traces the Mashrabiya to the Mamluk and Ottoman periods in Egypt (1517 ~ 1905) and their extended influence on Saudi Arabia (Almurahhem, 2008). Kenzari and Elsheshtawy (2003) and Alenazy (2007) clarify its use in Egyptian mosques, where it was used in order to create a separate space for the ruler after a series of assassination attempts against Muslim rulers at the time. Although this contradicts the spirit of Islam prayer, the new enclosure within the mosque and behind the wooden screens provided protection and the concealment of individuals for protection purposes while permitting social participation. This act was popularised during the Mamluk rule era (1248–1516) and the oldest example of Mashrabiya is said to have been used in the Great Masjid at Qayrawan (Almurahhem, 2008).

The flat screen base of Mashrabiya was made through woodturning. Developed in the Coptic period, wood craft created lacy appearance treatments that advanced even more during Ottoman times. Reaching its finest stage of design during the Ottoman period, ordinary people as well as royalty started to use the Mashrabiya screen in both exterior windows and interior hallway treatments. Figure 2-14 shows the fine Mashrabiya of the Gamal Aldin Aldhabi mansion in Ottoman Turkey, where women stayed behind to watch activities in the grand hall below without being seen.

The turned wood technique was the most widespread one, although lathing every wood piece and composing the geometry yet varying the openings according to the function was a skill-demanding craft. The later stages of Mashrabiya development sided the turned wood Mashrabiya as rare skilled craftsmen existed and the time of composing and turning was replaced by CNC-cut fretted work (Samuels, 2011).

Figure 2-14: (Left) Gamal Al Din Aldahabi Ottoman mansion Mashrabiya (1634). Source: flickr.com.

(Right) Abandoned turned wood Mashrabiya in Aljalawi wood workshop in Bahrain, 2014. Source: Author.

2.3.4 Materials and dimensions

A variety of materials and dimensions have been noted in Mashrabiya designs depending on their context and the availability of local materials. In Egypt, for example, quality wood was rare and expensive so craftsmen relied on turning the wood of small fine wood trees to make the screens.

Aljofi (2005) documents that care should be taken for the material used in the Mashrabiya to reflect light and thus influence the light quantity penetrating the interior. Considering wood as the most common Mashrabiya material, a reflectance rate of 10–50% can accrue depending on the form, features and finishing colour.

The dimensions of the Egyptian turned wood Mashrabiya depended on the window size it was meant to cover. Samuels (2011) represents the relation of the diameter of the turned wood pieces to the gaps in between them to calculate a Mashrabiya prosperity factor. See Figure 2-15.

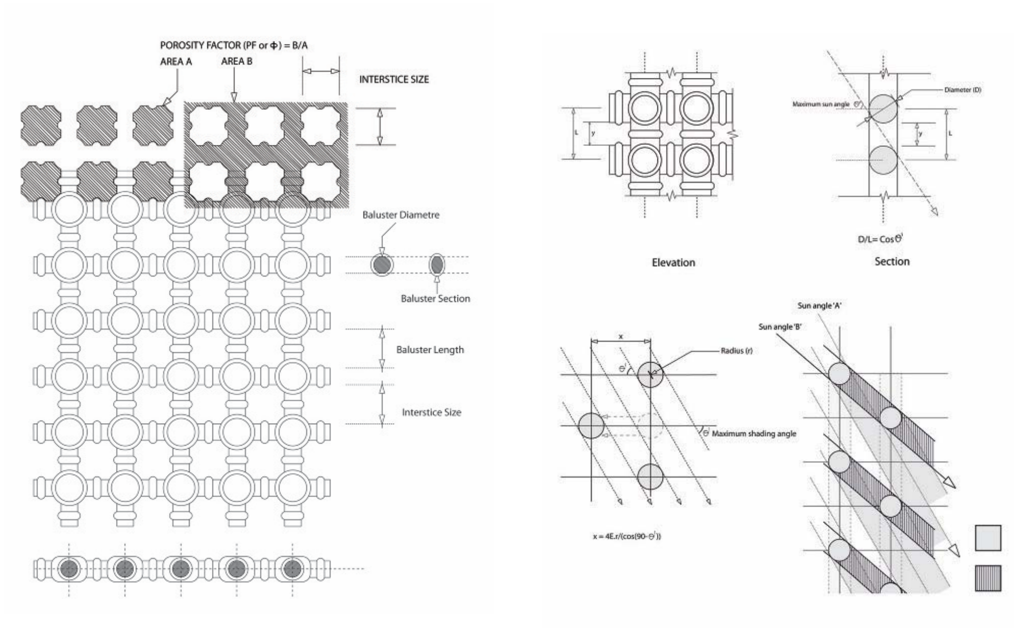


Figure 2-15: Samuels' (2011) drawings of Mashrabiya details.

The Bahraini Mashrabiya, seen in Figure 2-16, is simpler in detail and does not require a lathing mechanism to turn the wooden parts. The louvres are placed in the middle part and ornamental screens on its sides allow more light to enter the room behind. The window is fixed to the exterior wall after the building has been constructed and painted.

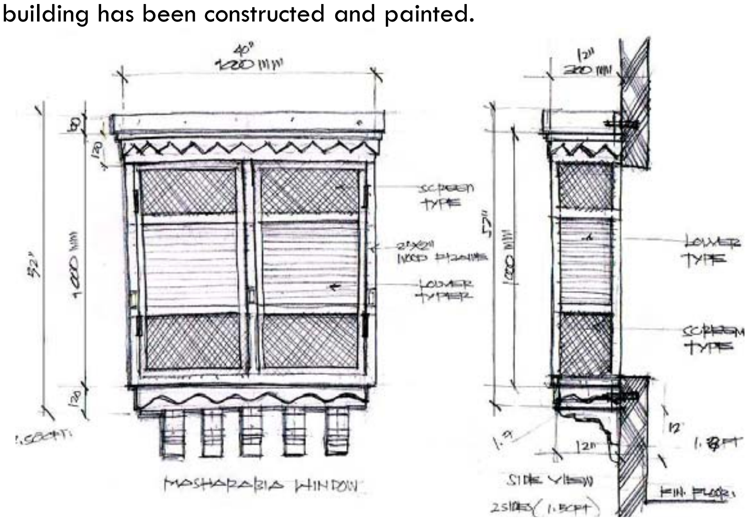


Figure 2-16: Wooden Mashrabiya drawn by Developers Wooden Furniture Factory based in Bahrain.

2.3.5 Mashrabiya typology in Bahrain

In the Bahrain context, the concept of Mashrabiya shading screens overlaps with three terminologies, *Karkari*, *Aggasi* and Mashrabiya. Misuse can be noted in the literature regarding the use of each; therefore, a definition is needed here to distinguish the role and appearance of its different types. The following chart summarises the three major types found in the literature and in photographs of traditional and modern Bahrain Mashrabiya; see Figure 2-17.

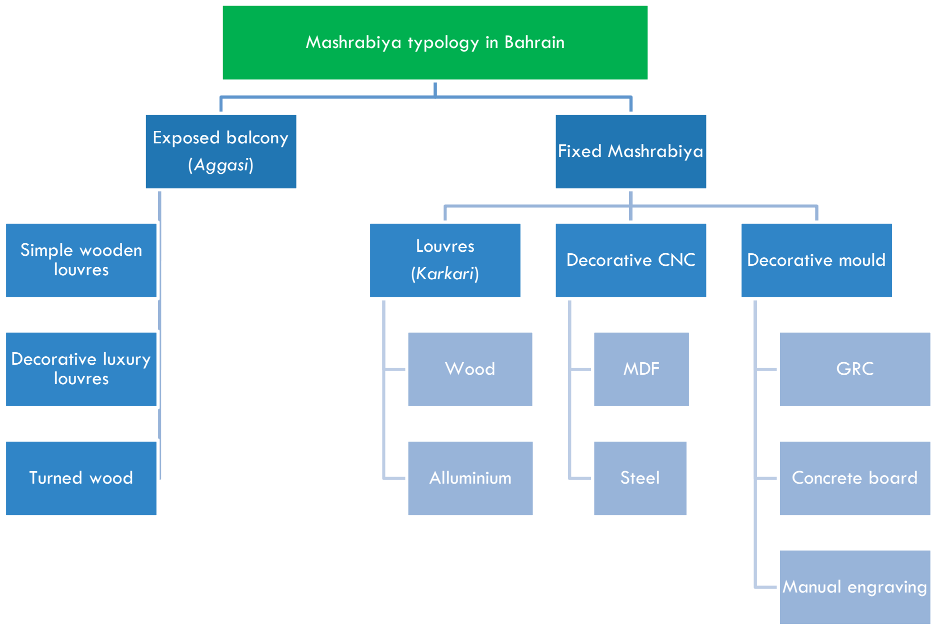


Figure 2-17: Mashrabiya typology in Bahrain. Source: Author contribution.

A Bahraini Mashrabiya is commonly a screen made of fretted wood panels or gypsum paste moulds and not from turned wood. It is widely used in traditional houses to cover windows that overlook public spaces or main roads.

The *Aggasi* is a closed projected balcony covered with wooden louvres named *Karkari*. Kazerooni (2002) claims that the nearby Persian architecture in Iran influenced the introduction of *Aggasi* balconies in traditional Bahraini architecture. The local name *Aggasi* or *akkasi* is derived from its functional role that reflects view 'akas in Arabic verb' as noted by the historical architecture architect Ahmad Aljawder through personal communication.

The role of the balconies varied between social and environmental. Similar to that of the Saudi *Roshan* noted earlier by Almurahhem (2008), the almost 90cm depth *Aggasi* enabled the women of the house and their neighbouring female visitors to overlook the activities performed in the opposite roads and logia in special ceremonies. Nevertheless, in contrast to the Roshan described and analysed by Almurahhem (2008) and overlapping with the Mashrabiya described by Sidawi

(2012) and Aljawder (2014), the Aggasi was an exterior part attached to the building facade and did not mediate with the interior. However, it is similar in it being a semi-closed projected balcony that conceals women and ventilates the space behind it.

As Kazerooni (2002) explains, the Aggasi wooden louvres point upwards to the exterior to push air inside and block the view of the outside. Moreover, they act as shading devices from direct sunrays and provide an air current inside. A small window opens to the outside within the structure of the balcony to allow women to gaze outside and communicate with the outside word. It is sometimes also used to communicate with merchants passing by or to overlook special religious customs like 'Mawakeb alazza alhussaini'.

Figure 2-19: Ali Reza House's Aggasi, Bahrain. Source: Author.

Figure 2-18: Researcher viewing the road from the Khalaf House's Aggasi small window opening. Source: Author.

The woodwork of these balconies varied between simple decoration to the advanced Iraqi craftsmanship seen in the Pearl Merchant 'Khalaf' house. His *Aggasi* and Mashrabiya utilised fine woodcraft and expensive solid wood, as seen in Figure 2-18 and Figure 2-19. It can therefore be concluded from the form and shape of *Aggasi* and *Karkari* that Bahraini houses developed their own Mashrabiya-like shading treatments that are derived more from the Iranian and Iraqi *Shanashel* than that of the Egyptian turned wood Mashrabiya.

The Mashrabiya terminology in Bahrain is more related to describing a fixed screen adjacent to window openings in traditional houses and composed of natural material (Aljawder, 2014). Wood and gypsum with lime work have been used in Bahrain since the Dilmmun period. Aljofi (2005) states that Mashrabiya designs are mostly composed of cells in a special organisation and measured thicknesses. The role of Mashrabiya, as proven by Aljofi (2005), is its ability to filter almost 51% of direct sunlight entering a space. This made it valid for use within Gulf traditional architecture.

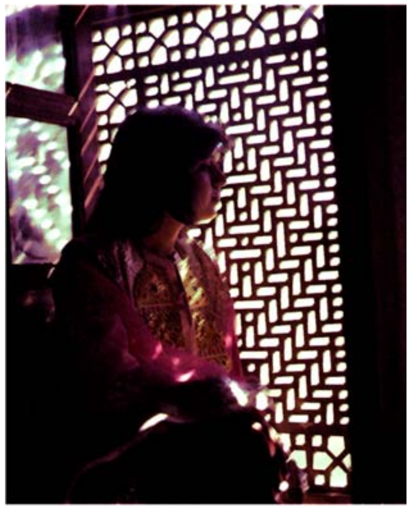


Figure 2-21: Decorative Wooden Mashrabiya in Sheik Ibrahim Alkhalifa's house. Source: Author, 2013.

Figure 2-20: Gypsum Mashrabiya interior view. Source: Photographer Abdulla Alkhan's archive.

If the Mashrabiya is agreed to be a shading screen used over windows, as shown in Figure 2-20 and Figure 2-21, then several new treatments may fall under it in Gulf architecture and interior design selection. The Karkari, which are the partial wooden louvres seen in Aggasi divisions, have become a treatment by themselves in low-income traditional houses. The role of the louvres is to serve the functions of privacy and ventilation. In modern housing, the wooden Karkari has been replaced by aluminium louvres that can withstand humidity unlike wooden ones. A new building law by the Bahraini Municipality has stated that high-rise building flats should use louvres when located overlooking a private house, as discussed earlier. This was initiated in 1997 to ensure the privacy of the overlooked houses.

CNC-cut wood, aluminium, wrought iron and steel sheets started appearing in the window shading of new development projects. Later, they extended to general public housing in a race to distinguish houses through affordable facade treatments. The Abiya Company, based in Dubai, can be considered a leading company in Mashrabiya production, generating a new design and developing an algorithm-based geometry program using CAD and Advanced CNC machines, as seen in Figure 2-22.

In recent interiors, the researcher has distinguished a new trend of fixing fake Mashrabiya in a nostalgic call for traditional Bahraini themes in shopping malls, high-rise buildings or luxury hotels. The fake Mashrabiya fixed to a blocked wall displayed in Bahrain City Centre's *Souq* or traditional market area is a standing example of this fake nostalgia, as seen in Figure 2-23.

The trend of reviving cultural and heritage elements is gaining more popularity in Bahrain and the Gulf region. Reusing traditional architectural elements is a design trend seen when applying a

Bahraini style to a modern restaurant serving traditional food or even in graphics while branding Arab and Gulf identity. This design trend can be considered in itself a phenomenon worth studying. Nevertheless, the focus of this research aim can be supported by this trend to revive historical architectural elements like Mashrabiya to blend with modern interiors.

The existing problem is the lack of a conceptualisation source to generate new patterns and design forms. Imitating old forms once fitted traditional houses but this is not the case anymore. The introduction of air conditioning and new manufacturing makes it possible for many products to be upgraded if thoughtful design consideration is articulated during the design and manufacturing phase.

A true understanding of architectural element construction details, like the Mashrabiya, should be documented, understood and tested with new materials and manufacturing before being used in modern interiors. This is partially the aim of this research, and the following section highlights the documentation phase in more detail.

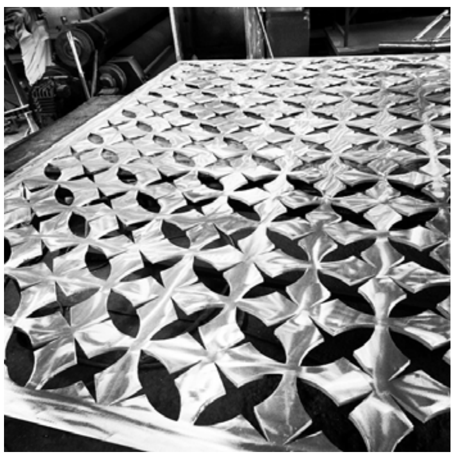


Figure 2-22: Aluminium Mashrabiya by Abiya.

Figure 2-23: Bahrain City Centre Mall Mashrabiya.

Figure 2-24: Basta 23 Restaurant in Bahrain Reyadat Mall. Source: google.com

2.3.6 Design and construction details

The external details of Mashrabiyas are based on their criteria and place of manufacturing. Samuels (2011) notes that although the detailing and style of Mashrabiya screens sometimes changes between countries, the functionality of the screen remains the same. According to Aljawder's (2014) research in Bahrain the 'screen type' is more popular than the Egyptian lath type or the Saudi exposed balcony type or *Roshan*. For the sake of referencing, documentation and later comparison, all three types will be illustrated in this research section. The visual illustration in Figure 2-26 by Mortada (2014) represents a full documentation of the Jeddah Mashrabiya and Roshan typology. His model of Mashrabiya indicates the screen part of the Roshan that provides visual privacy to the window openings within the Roshan projected form. Ragette (2012) in Figure 2-25 shows the relationship between the veiled woman and the Mashrabiya or Roshan. The privacy obtained is balanced by the cooling effect and daylight she enjoys.

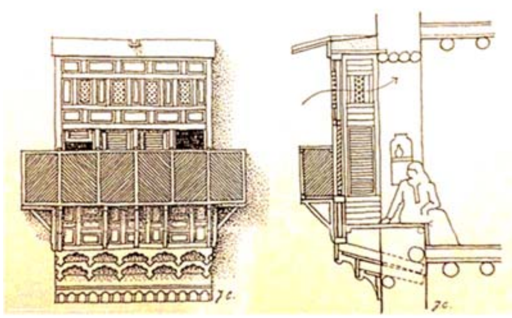


Figure 2-25: Saudi Roshan. Source: Reggette (2012, p. 207).

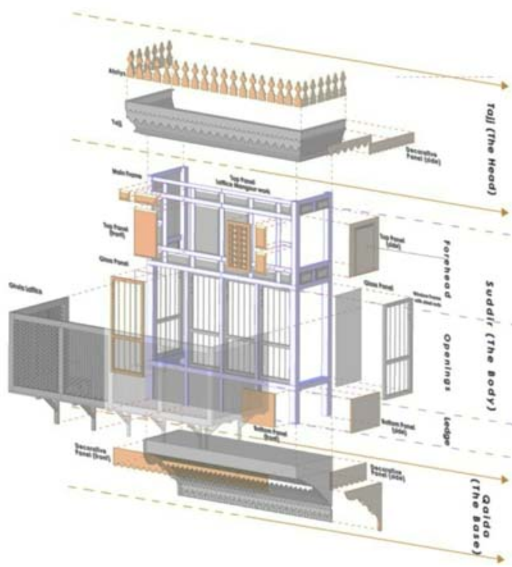


Figure 2-26: Mashrabiya and Roshan construction. Source: Mortada (2014)

As categorised earlier in Figure 2-17, Mashrabiya can be manufactured out of several materials. The traditional material used was determined by its affordability and the social status of the householder. Rich owners, as stated by Kazaroni (2009), could afford imported expensive solid wood. Teak and cedar wood seemed to be the favourite choice, as noted by Bendetti et al. (2010). Low-income owners used louvres made of palm trees and soft wood. Unvarnished solid wood is considered capable of withstanding the heat and humidity of Bahrain. However, palm trees and cheaper wood types deteriorate after a while as a result of the harsh environmental conditions. The new material used for Mashrabiya decorative screens, such as aluminium, has better resistance to humidity and heat. However, the materiality of new Mashrabiya has rarely been investigated in the literature. The most recent study was conducted by Bendetti et al. (2010) and proved that solid wood would function best in terms of its evaporative cooling characteristic.

Another common traditional material for Mashrabiya screens in Bahrain was gypsum. Limestone were burned, crushed and mixed with water to create gypsum paste. The paste was used over wooden moulds that can be carved by craftsmen. The process was time-consuming and labour intensive. Simple tools and knowledge of geometry were needed. Nowadays, Glass fiber Reinforced Concrete (GRC) panels have dominated the facades of several housing projects in Bahrain since the 1970s. The ready gypsum powder imported from Saudi Arabia speeded up the process, along with rubber moulds. The aim behind using such screens targeted the cooling effect of gypsum and the traditional look and identity it added to housing facades. The traditional gypsum moulds were hand carved while the new GRC panels are sometimes imported ready-made from other markets like China. The current manufacturing of GRC, as seen in Figure 2-28 and Figure 2-29, still relies on the manual work of foreign craftsmen.

Figure 2-28: GRC screens made by Dar Alkhaleej factory. Source: Author and her students.

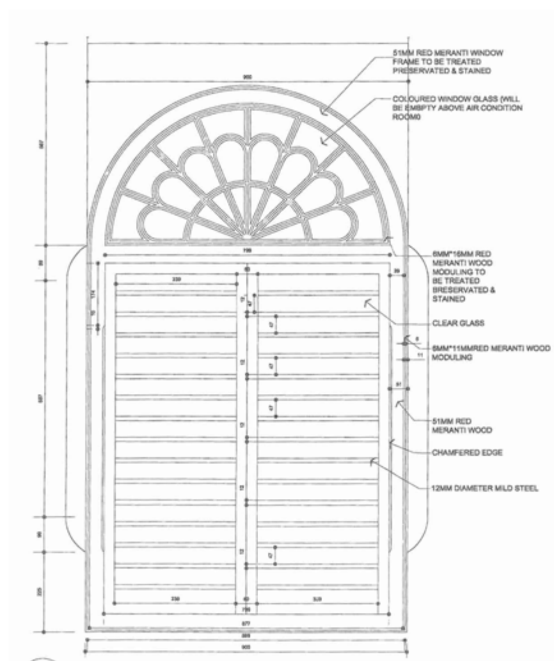


Figure 2-27: A typical wooden louvre-type screen used in the Souq Alqaysareya renovation project. Source: Bahrain Ministry of Housing.

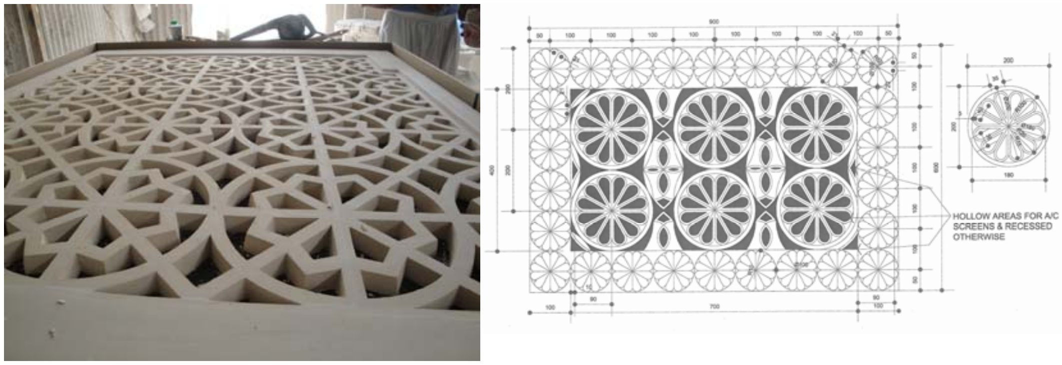


Figure 2-29: A typical gypsum screen pattern. Source: Bahrain Ministry of Housing.

2.3.7 Function of Mashrabiya in the Bahraini context

The functionality of traditional Mashrabiya remained focused mostly on privacy and ventilation in domestic Bahraini houses. Light control was not included in the design of Bahraini fixed Mashrabiya. The individual balusters of Mashrabiya were used to create a visual barrier to conceal the women of the house. Thus, Aljawder (2014) emphasises how old Mashrabiya allowed the inhabitants of the house to view the street but not to be subject to being viewed from outsiders. She explains how the darkened interior was outshone by the brightness of the Mashrabiya wooden balusters. The situation would be the opposite for those inside the building. Alenazy (2007) adds that an added aesthetic function of Mashrbaiya screens is to evoke an expressive shadow. The shadows created can accentuate the feeling and shape of an interior space.

Another view on the subject is Kazerooni's (2002) demonstration of the use of traditional Mashrabiya louvres with an upward lifting orientation as a key connection to the sky. In his opinion, this served three purposes. The first was to avoid overlooking the streets and the neighbouring houses. And the second was to be spiritually connected to the sky. The last was to allow a nice breezy airflow to enter the space and cool it in a passive manner. Yet, passive cooling can be argued as being inadequate for Bahraini new houses. The high level of humidity and the introduction of air conditioning systems in modern houses has placed an emphasis on the aesthetic function of Mashrabiya rather than environmental ones.

Nevertheless, the factors of visual privacy and daylight adequacy have been proven to be currently valid in Aljawder's (2014) research in the field. The screen has lately evolved to become just a shading device placed outside the windows for privacy and safety reasons. The majority of modern houses look more Westernised, as explained previously. Some owners might consider the use of Mashrabiya as a traditional-looking treatment that should be avoided. Occasionally, new modern houses might use GRC screens for decorative purposes. Privacy is ensured with a supporting interior curtain or roller blinds. It can be concluded that the Mashrabiya has gradually lost its place in the architecture of modern Bahraini villas and buildings.

In terms of the environmental aspect, the Mashrabiya plays a role in cooling and humidifying houses. The Mashrabiya's wood absorbs, retains and releases water when faced with an air current. Once the wood fibres get heated by sunlight they release their retained humidity. Kamashki's (2015) experiments related the size of the openings and the area of Mashrabiya to its cooling and humidification role. He found a drop of around 0.5°C in room temperature where Mashrabiya screens are used in Bahrain. In conclusion, Samuels (2011) ascertains that the decline in the use of Mashrabiya within the Middle East resulted in the loss of a huge wealth of Mashrabiya craft knowledge and its sheer aesthetic value that once dominated the streets.

2.3.8 Mashrabiya characteristics

VIRTUOUS ATTRIBUTES

Islam is considered by its practitioners as the religion of peace and virtue, where women's modesty should always be preserved, as explained earlier. Families' and women's rights to privacy was guarded by Mashrabiya. Almurahhem (2008) and Laurette (2006) relate the concept of Mashrabiya to women's Islamic hijab or veil as an outer garment to the house. Traditional Bahraini houses praised the notion of privacy and security as a dominant concept of the Islamic culture and religious practices. Moreover, the Mashrabiya is considered by Kenzari and Elsheshtawy (2003) as an architectural veil that is similar in function to women's textile counterpart. House owners would cherish their privacy and preserve it from outside gazes as they would do the same for their female relatives.

Creating socially engaging conditions is another merit of Mashrabiya. The women of the house and their neighbouring female visitors can gather behind Mashrabiya and overlook the street (Samuels, 2011). Almurahhem (2008) describes a sensory experience that indulges the senses behind those screens. Thus, Mashrabiya allow children to be heard outside playing, smelling and touching as well as it being possible to speak to outside sellers from their windows. The space behind the screen therefore can work as a mediated interior yet exterior experienced space.

DEFECTS

The defects of the Mashrabiya can be argued to relate to its appearance, new functionality, materiality, cost and innovation rhythm. To explain, the appearance of the Mashrabiya is now being viewed as a "traditional element" that conflicts with the modern image users are expressing in their villas or apartments (Samuels, 2011). Dayrantene and Karajica (2009) and Samuels (2011) note the influence of imported Westernised architecture on the alienation of Mashrabiya within new house designs.

Although the Mashrabiya has a ventilation role, the new air conditioning systems and double glazed windows removes this function from Mashrabiya and left it as an ornamental peice. Bahrain's good weather mostly runs between December and April yet people do not open their windows during this time as cold temperatures can infiltrate the houses that are mostly designed without any heating systems.

Abdelgelil (2006) and Aljawder (2014) state that the traditional Mashrabiya is expensive. It relies entirely on the availability of suitable materials and manufacturing techniques. Solid wood is highly expensive but can withstand heat and humidity. Aljawder (2014) calculates that one metre square of a thickness of 4cm can cost about $300. On the other hand, lathing, fixing and carving Mashrabiya can be time-consuming. Craftsmen specialising in Mashrabiya making are rare in Bahrain. This had a negative influence on the rhythm of innovation in the Mashrabiya type of architecture. With the introduction of mechanised production in 2000, CNC Mashrabiya started to be reused as a new decorative screen. Although CNC Mashrabiya might allow low production costs, the pattern and form needs more design and innovation work to make the screen a valid sustainable option, as it once was.

2.3.9 Methods of response

ENVIRONMENTAL RESPONSE

The Mashrabiya responds passively and positively to its surrounding environment. Sherif (2012) proved the influence of the screen depth and perforation on decreasing the heating, cooling and lighting energy loads in its environmental surroundings. The screen was also found to reduce the penetrating light level causing glare (Saridar, 2000, cited in Vaklinezhad et al., 2013). Alshareef's (1996) debate summarises the use of Mashrabiya and Roshan to cool water jars in Islamic cities. He classifies these products as having more of a climatic character than a privacy role.

The screens also allow a good passage of air and breeze. Hassan Fathy (1986) states that the Mashrabiya is the best solution for thermal comfort problems in the region. This is because its design hinders the flow of heat into a building. At the same time it has a positive effect in enhancing a cooling effect. Allyai (1990 cited in Aljofi, 2005) also investigated air movement in various areas of a traditional house in Jeddah City. An indication of an increased air velocity of about 0.3 to 1.3 m/s was recorded.

Airflow simulation and shadowing evaluation gave Benedetti et al. (2010) the ability to determine the relation between the cooling effect and the geometric aspect of Mashrabiya concerning natural ventilation and solar control. Both Benedetti et al.'s (2010) and Aljawder's (2014) simulation regarding the illuminance values of the screens proved the visual comfort level gained from Mashrabiyas.

SOCIAL RESPONSE

The production of Mashrabiya is related to Muslim women's veil, as noted by Kenzari and Alsheshtawy (2003). The veil and its relation to visual privacy has been well studied by Aljawder (2014), who argues that, as have other scholars such as Almurahhem (2008), that it is based on Quranic verses. One of the Quranic verses that regulates interactions between men and women to preserve women's privacy is cited here:

> *"Tell the believing man to reduce some of their vision and guard their private parts; that is purer for them, indeed Allah is acquainted with what they do. And tell the believing women to reduce some of their vision and guard their private parts and not display their adornment except that which ordinary appears thereof, and to draw their heads' cover over their chests and not display their adornment except to their husbands, their fathers, husbands' fathers, their sons, their husbands' sons, their brothers, their brothers' sons, their sisters' sons, other women, which that the right hands possess, or those male attendants who have no physical desire, or children who are not yet aware of the private aspects of women, and let them not stamp their feet to make known what they conceal of their adornment and turn to Allah in repentance all of you believers that you might succeed" (Quran, 29, 30: 24).*

The notion of the veil being like a second skin to women was examined by Kahf (cited in Heath, 2008). Kahf explains how a woman's veil can create a personal space around her, but what if the veil type changes and evolves through time? Can that define a new space? With reference to the Quran, it can be noted here that the religion guides the architectural practice and its elements in a Muslim society, as explained earlier in Chapter 2. The social act is derived and affected by the religious beliefs of such a society. The evolution of society, however, is also related to other driving forces. Industry, politics, technology and wealth have had a huge influence on Muslim societies in Bahrain, as in many other Gulf regions. A new type of veil appeared and developed within female circles that may be reflected in house architecture. Elan (2015) claims that the fashion world made a huge impact on the story of *Abaya (women body and head robe)*. The driving forces of this change is controlled now by social media apps like Instagram and international bloggers' viewpoint as noted by Khondker (2011).

As a concept the notion of a veiled women in traditional Bahrain before 1920 took the form of a head abaya. Abaya, as explained by Knox (2012), is a black loose dress or robe that covers women's bodies as an act of responding to society's traditions and religious beliefs. The abaya perfectly responded to the Islamic dress code. Women would wear an abaya over their domestic garments while outside their homes. By the 1990s, the oil wealth resulted in a new fashion industry aimed at religious women in Bahrain and the Gulf region. The emergence of this trend offered clothes and head scarves especially designed to maintain religious modesty without sacrificing fashionable flair (Knox, 2012). Many new abayas are made by order to match the Muslim women's Italian or French designer brand accessories.

A new branded veil dominates the market today in Bahrain. For some, this is contradicting the aim of having a veil to protect women and their anonymity. In contrast, women in Bahrain today have the choice of veiling or unveiling in public places. Reflectively, this discussion of women's veils is directly tied to Mashrabiya and its alienation in modern houses. This is not only because modern women are not forced to wear a veil anymore but because screens like Mashrabiya might form an image of the traditional Bahraini women that 21st-century women would like to overcome.

2.3.10 New applications

The role of Mashrabiya as a privacy and environmental controller with its complex design geometry made it an aesthetically appealing yet functional product in traditional architecture. Moreover, it made it a source of much reinterpretation and new concept regeneration. The next section describes how the concept of Mashrabiya was reused in the architecture scale, interior design and product design domains. The later part describes how the shift emerged from focusing on manual craftsmen's skills to digital craftsmen's abilities to shape new Mashrabiyas.

ARCHITECTURE, INTERIORS AND PRODUCT DESIGN MASHRABIYA APPLICATIONS

Modern interpretations of the Mashrabiya concept from several architectural, interior design and even artistic pieces of work are seen around the world. This is due to the previously explained role of Mashrabiya as a sustainable indigenous design solution and an environmental yet social phenomenon. Figure 2-31 categorises some of the most recent projects inspired by Mashrabiya under three categories. The reliance on the Mashrabiya concept as a second skin or a structural pattern and finally as a visual element of cultural identity and value has become popular lately.

In architectural practice, the environmental value of Mashrabiya is well known. As reviewed by Abdelsalam and Rihan (2013), many architects put forward Mashrabiya interpretations in new projects in the Middle East. They have traced three sustainability trends, taking the Mashrabiya as an example to revive and interpret. The modern trend, the neo-traditional and the contemporary trend are explained briefly in the chart below in Figure 2-30.

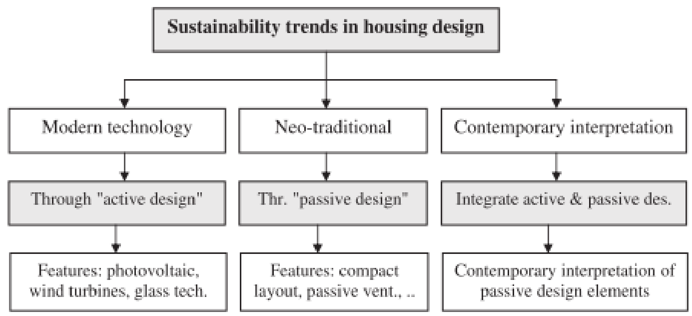


Figure 2-30: Sustainability trends in housing design. Source: Abdlesalam and Rihan (2013, p. 170).

For example, the Albahar tower project by Aedas (2012) and the Oxygen Villa (2012) designed by the Egyptian Studio House aim to produce an architectural envelope that can respond to daylight and the direction of the sun. Another innovative Mashrabiya in the field was designed earlier by Jean Nouvel's Arab Cultural Institute of Design in France (1987). The concept of creating a Mashrabiya window that reacted to sunlight like a camera lens aperture was considered by reviewers to be groundbreaking. Unfortunately, Nouvel's Mashrabiya was subject to mechanical failure a few years later. The modern smart adaptive skin of the Albahar Tower project wins the contest due to its intelligent Mashrabiya design and environmental context interaction. It uses parametric design and simulation as well as specialised programming methods and thermal actuators that open up the Mashrabiya facade like an origami fold.

Scaling up the Mashrabiya concept to that of a structural membrane was evident in other project trends around the MENA region. The variation of opening to provide sun shade is seen in Saint Joseph University (2011) in Lebanon as well as King Abdulla University for Science and Technology (2012). Relying on local materials to cut building costs and achieve maximum functionality, the brick Pattern House in Iran (2012) embodies two important aspects: the combination of a local Mashrabiya structure made of local materials and the empowerment of craftsman skills transformed on an architectural scale.

The third category of Mashrabiya interpretation on an architectural scale relies on its shape and visual characteristics. Almerbati et al. (2014), refer to Appendix A, explain how Islamic identity and cultural values are recalled together in the coming examples. The first is Masdar Sustainable City (2010) and its GRC Mashrabiya units designed by Foster and Partners. The abstracted screen patterns of Masdar residential apartments are argued to provide visual privacy and shading to the streets which they overlook. Moreover, the low-cost GRC panels were moulded in a semi-circular form to give smoothness to the facade. Additional cases of the Mashrabiya can be seen in the Mashrabiya House of Palestine (2011) building as well as slide-S's (2011) conceptual proposal (Almerbati et al., 2014).

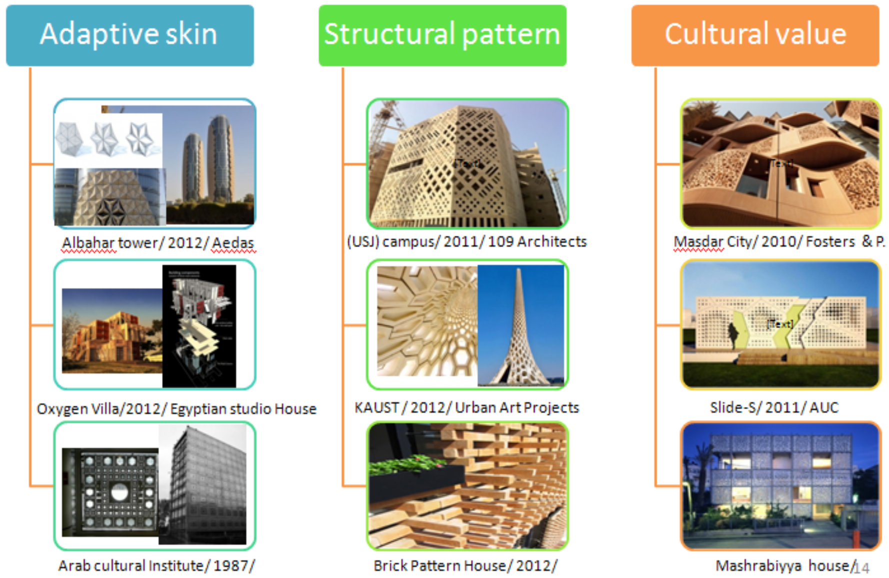


Figure 2-31: Mashrabiya in the context of modern architectural projects. Source: Almerbati et al. (2014).

Within interior design, the Mashrabiya screen was used in houses, offices and embassies to reflect cultural Islamic identity. It was also used to reflect the complexity of Islamic architectural patterns, and its aesthetic endorsement of interior space quality. It was used as a window screen and sometimes as a room partition. Material and weather conditions regulated the use of Mashrabiya in an interior space. Figure 2-32 displays the different interior applications of the researched element. The basic passive cooling function of the shading device was enabled by the beauty of the play of shade and shadows of its openings. Different manufacturing techniques are being utilised, as seen in the CNC project recap 2 (2009) screen or the clay screen titled ecooler (2010). The ecooler utilises water to perform a passive cooling effect on the interior like an old clay water jar. A distinguishing new feature is the incorporation of writing as introduced by Suzan Hefuna's (1997) artistic Mashrabiya. Her Mashrabiya goes beyond visual beauty to promote dialogue between languages. The messages and sentences encrypted within the Mashrabiya design Hefuna creates can be read from a distance which has a reflection on the façade identity and initiate hidden dialogue between the users and the observer.

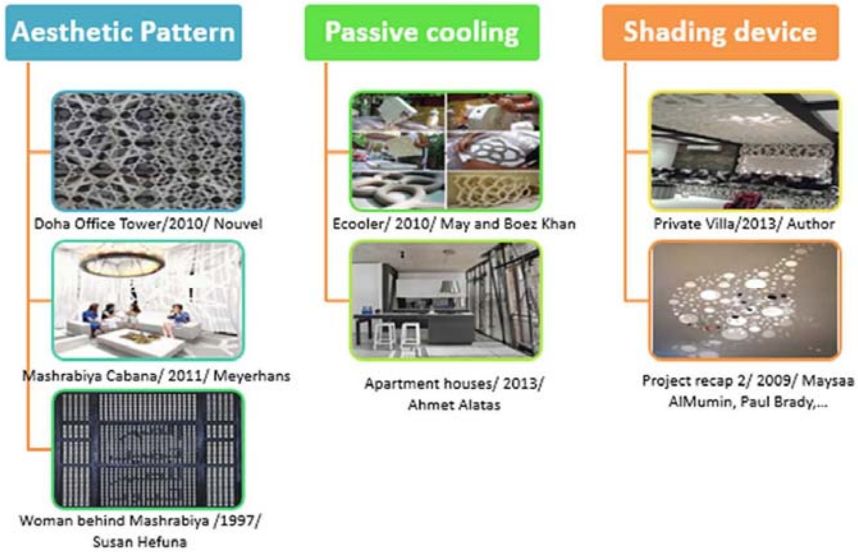


Figure 2-32: Mashrabiya's role within interior design context. Source: Almerbati et al. (2014).

Moreover, the Mashrabiya pattern and screening effect are used in product design. Furniture pieces of lathed parts like the Mischer'traxler table or Benabboud's patterned armchair in 2011 are good examples of this trend, as illustrated in Figure 2-33. It is important to note here that the form relies merely on the nostalgia of the traditional effects these pieces can bring to a space. They might also be considered as samples of the neo-traditional movement but in furniture not architecture, as explained earlier by Abdelsalam and Rihan (2013).

Figure 2-33: Furniture design inspired by Mashrabiya. Source: Almerbati et al. (2014).

"*Culturally made materials*" are defined by Grier (1996) as materials that take into consideration the "biosocial environment" of a cultural building or landscape. This subject may interest historians of architecture, design and arts as well as technology. A valuable collection of products or artefacts of cultural significance are very important in understanding the lifestyle and norms of a group of people and their interactions with their environmental context and time. 'Material culturists' believe that the study of objects and artefacts and their circumstances of making can reveal unique perspectives of data that are not well documented. Islamic architecture and culture is a rich intriguing example with its delicate and geometrically advanced artefacts and production (Kaplan, 2002).

Historical data can significantly influence the current and future design of architectural facade treatments that could comply with the harsh environmental conditions in the Middle East. More urgently, architects from these Islamic countries (Wally, 1993; Abdelgelil, 2006; Almurahhem, 2008; Eldemery, 2009; Ajaj and Pugnaloni, 2014) have been calling for a realistic and cautious revival of the Islamic identity archetype by collaborating with modern technology instead of the mere 'copy-paste' of forms noticed by Omar, cited in Sidawi (2012). Abdelgelil (2006) also notes that in 1995, the Egyptian Ministry of Culture and IRCICA hosted "Crafts in Traditional Islamic Architecture", the first academic conference to focus on Mashrabiya. The recommendation of the paper presented agreed that Mashrabiya should be revived, improved and adapted to the contemporary Egyptian lifestyle.

The following part of the chapter will focus on four cases from academic research, the production market and an architectural product concept that have used either craft skills or parametric data and technology to define their final product. The criteria for selecting these projects were their dependency on the combination of manual or digital craftsmen's skills.

Mashrabiya vernacular architectural construction requires significant craftsmanship in developing the individually hand-turned parts that work together in the overall assembly; see Figure 2-34. As these craftsmen have become more and more scarce, the architecture has continued to become cartoon-like. As a result, the performative functions of the screens have simultaneously disappeared. The high cost of manufacturing these constructions and maintaining their performance is simply no longer feasible under the historic model of construction (Abdelgelil, 2006). Similar to the notions of '*Undrawable Architecture*' documented by Dritsas and Yeo (2013, p. 834), these constructions are

> *"… underpinned by tacit tectonic knowledge passed along generations which were never formalized, and a product of artisan craftwork of phenomenal complexity that was manually re-produced but never rationalized."*

Figure 2-34: The luxury craft of Mashrabiya making. Source: https://www.youtube.com/watch?v=JFiaVEWG3gs

1- Mischer'traxler gradient Mashrabiya table (2012)

The designer Mischer'traxler, in collaboration with digital and manual craftsmen, envisaged a new product commissioned by the Carwan Gallery. He relied on the skills of a Lebanese woodworker and CAD software to create a table that visualises how Mashrabiya elements are crafted and composed.

Figure 2-35: Gradient Mashrabiya by the Mischer'traxler studio. Source: http://www.mischertraxler.com

He captured the complicated process of lathing around 650 individual elements and assembling them together, emphasising the difficulties of the Mashrabiya craft. However, the challenge became more manageable by following the CAD drawings as a guide (Figure 2-35). The concept, and the time and energy put into displaying this product at the Saudi Arabia Design Festival and Dubai Design Days in 2012 was well spent and it fits the culture it targeted in the Middle East. A point to raise here is that this product does not rely on the social or environmental value it is originally derived from. It has been designed for aesthetic and geometric purposes only, and the value of a national Arab identity.

2- Mey and Boaz Khan's ecooler (2010)

In their heat-beating product, named ecooler, the Israeli designers Mey and Boaz Khan based their design on the environmental and light infusion character of Mashrabiya screens and old clay jars. The merging of the two concepts into a network of hollow mould clay pieces allowed water to cool the tiles and the air that passes by them; see Figure 2-36. Although this product might be aesthetically appealing and conceptually interesting, nevertheless it can be said that it will not be efficient in a hot and humid climate. This is a product that carries the identity of the Orient but cannot be adjusted to fit several contexts or scales as the crafting technique is limited to the mould that has been created.

Figure 2-36: ecooler concept and construction.

Source: http://www.greenprophet.com/2010/10/mey-boaz-kahn-ecooler/

2- Samuels' CIM and CNC Mashrabiya model (2011)

In his research titled 'Performance and Permeability' William Samuels (2011) took a conscious environmental decision to construct a Mashrabiya-inspired screen to be used in Australia. The researcher takes into consideration sun, light and materiality as well as the visual quality created by each model's proof of concept. The few models he created relied on the digital craftsman skills he acquired and were supported by the scientific knowledge obtained. Even if the final result was not aesthetically significant, the process and the product created utilised modern technology of CIM and CNC that was not available to local craftsmen; see Figure 2-37.

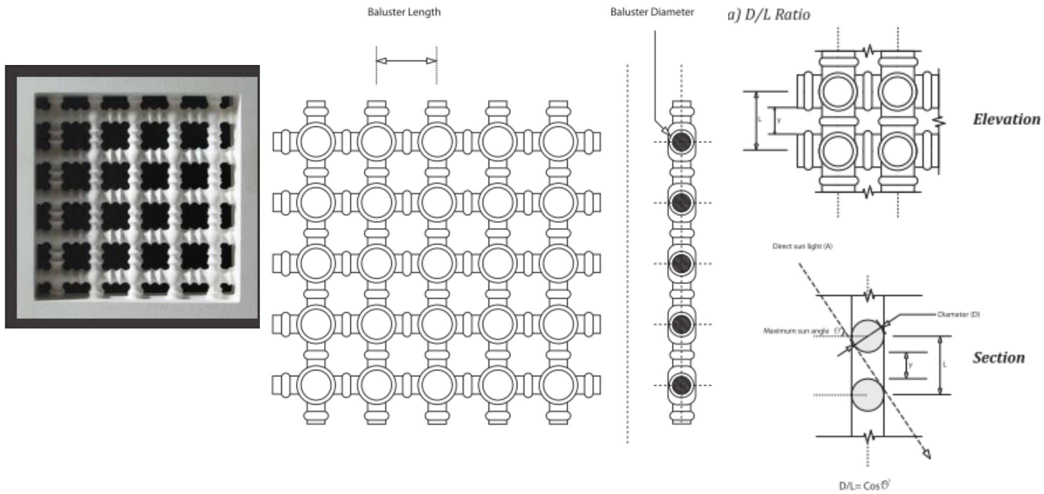


Figure 2-37: Samuels' sample of designed Mashrabiya-inspired screens. Source: Samuels (2011)

3- Emerging Objects' 3D-printed Cool Brick (2015)

Using the new parametric and modelling algorithms, Emerging Objects used 3D printing to re-conceptualise a thermal cooling brick based on the Mashrabiya concept or what they called 'Frescoes'; see Figure 2-38. A hollow brick resembling the porous water jar was created, duplicating the concept of the ecooler. The benefits seen in this product are its utilisation of the abilities of a digital craftsman or artist to design the pieces and the ease of use of 3D printing as a mode of production. Unfortunately, this conscious thought may also prove to be impractical in the cultural context. Passive cooling through hollow bricks can also mean that air conditioning can escape the interior, and the holes might also be a great place of shelter for insects and humidity rot. It might need to be scientifically tested to prove its environmental efficiency.

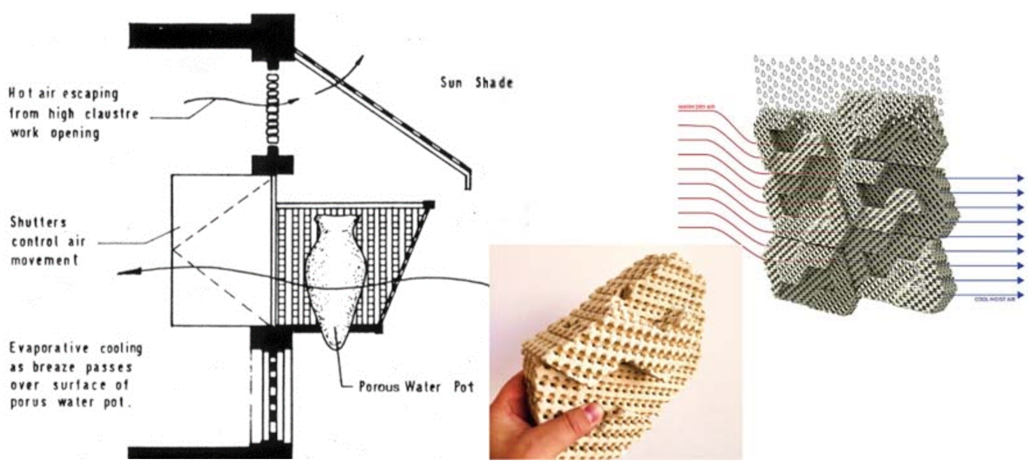


Figure 2-38: Cool Brick by Emerging Objects 2015. Source: http://www.emergingobjects.com/projects/cool-brick/

In Bahrain, CNC-cut wooden sheets, gypsum or GRC moulds have provided good substitutes for wooden Mashrabiya. These are especially used by low-income families and housing projects. Both produced Mashrabiya that responded to the climate, temperature, and visual privacy aspects; however, thermal and noise control is still questionable. Unfortunately, because of the manufacturing technology and finishing quality, the form of the new Mashrabiya became a solid mass of heavyweight objects.

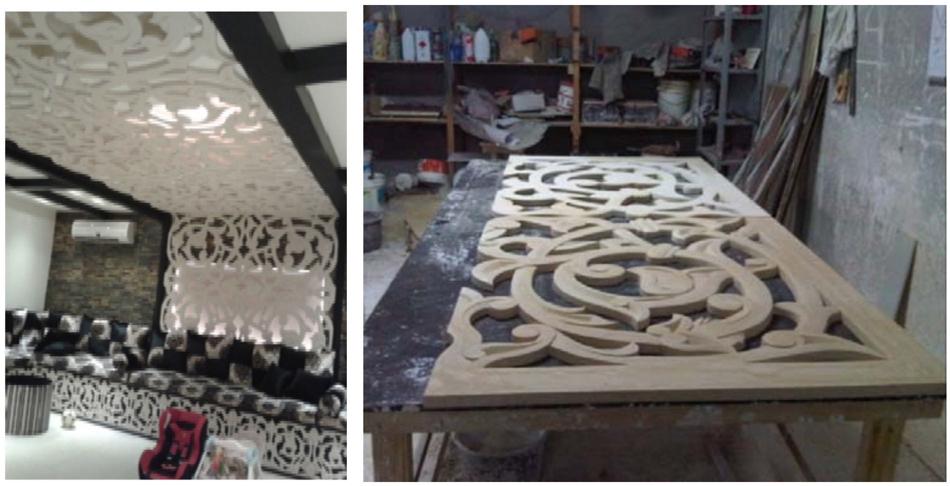


Figure 2-39: Moulded GRC heavy Mashrabiya fixed in a residential interior. Source: Author.

It also became an element that cannot be opened to benefit from the outdoor night breeze. In a new design trend to save this relatively expensive element from deteriorating in the extreme weather conditions of the Gulf, the new Mashrabiya product is now fixed from the interior side of a window; see Figure 2-39. This decision definitely needs further investigation as it is against fire escape regulations, causes a lot of dead load, and simply becomes an unopenable barrier preventing inhabitants from benefitting from the breeze outside.

In conclusion, culturally made products rely on local manufacturing techniques or the adoption of regional trends in order to evolve. The development of Mashrabiya as a cultural element can be bounded to the technology of the context or to a combination of using global techniques to fit local contexts. The following researchers supported their design of a new Mashrabiya using an imported global technique, a local material, a new manufacturing technology or a combination of all of these factors. Abdelgelil's (2006) proposal relied on combining the design guidelines of the Japanese window treatment titled Machiya-goshi with local Egyptian fine wood carpentry. The final product can be considered a simple, flexible and affordable screen that would best serve Cairo's new social and economic standards. However, a negative aspect of her design can be noticed in terms of the extreme simplicity of the design that lacks the Islamic ornamentation aesthetic appearance seen in traditional Egyptian Mashrabiya. This can raise the question of future users' acceptance with regard to his/her facade's aesthetic appearance.

Samuels (2009), on the other hand, proposes a more interesting design interpretation of the traditional Mashrabiya using computer numerically controlled milling (CNC) and ceramic injection moulding (CIM). His awareness of new manufacturing technologies has helped him in proposing not only aesthetically appealing contemporary design solutions but thermally efficient ones for buildings in hot and arid Australia. Samuels' material selection and manufacturing can be considered successful when compared to Benedetti et al.'s (2010) hardwood and softwood Mashrabiya experiment. The latter relied on local and imported wood to implement the thermal performance of a new proposed Mashrabiya for Italy. Their research method, program simulation and real-life fixing and testing of a manufactured new Mashrabiya set a scientific approach for this product design.

Abdelgelil (2006), Samuels (2009) and Benedetti et al. (2010) have responded and relied on the guidelines of Hassan Fathy (1986) in their new designs; see Figure 2-40. Fathy promoted the use of affordable materials and simple Mashrabiya construction to be similar to that of the affordable Egyptian Sheesh or wooden louvres. His intention was to revive Mashrabiya regardless of its skilled craftsmen base, as it best serves the regional environmental and social contexts.

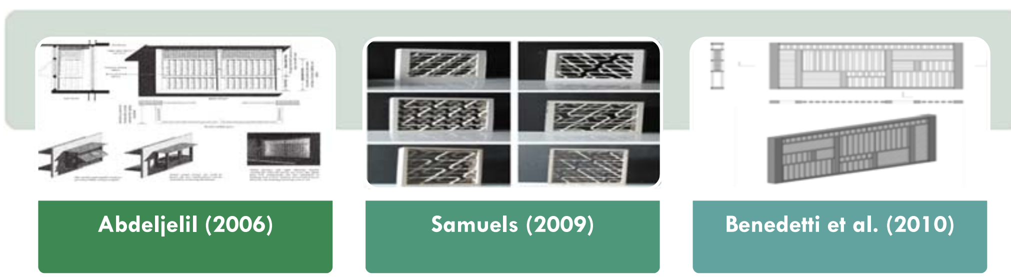


Figure 2-40: Peer-reviewed new manufactured Mashrabiya samples.

Two conceptual scientific models of a new shape of Mashrabiya were found in the literature with reference to their shape and daylight performance. The first model designed by Alshareef (2001) calculated the relation between the opening angle of the louvres and the amount of daylight entering the room. The second model was designed by Karamata and Andersen (2014), who designed a shape variable Mashrabiya (SVM) and calculated its efficiency as a shading and daylight system for arid climates; see Figure 2-41. Both researchers developed a set of scientific equations and virtual models to validate their conclusions. The SVM is made of three identical opaque perforated shields. They can move relative to each other to vary between a closed and an open configuration. The SVM has been proven to be capable of maximising visual comfort and minimising solar gain. The SVM, like that described in Abdelgelil (2006), is designed to switch between an open and a closed configuration. This flexibility in design allows control of the privacy level and sunlight.

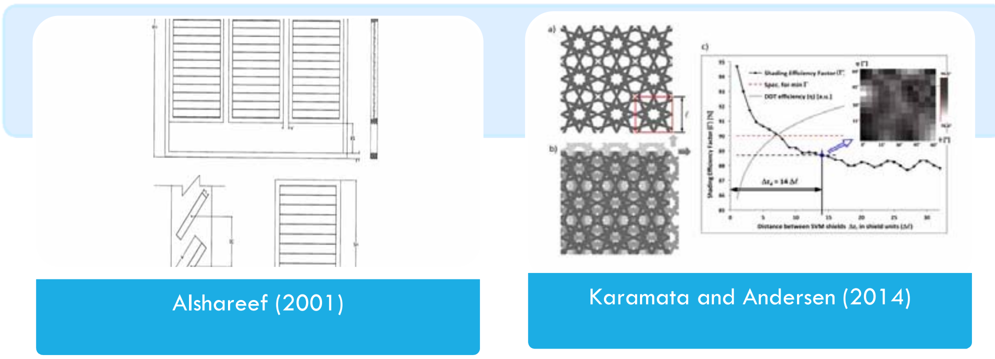


Figure 2-41: New research into Mashrabiya simulation.

Looking at the subtractive manufacturing methods in the market now, Mashrabiya is still expensive to build and replicate. Nevertheless, a pioneering thought here can be sourced to Postler and Ferguson (2009), a UK-based design company and the conceptualisers of the Microclimates project proposal. The company in its significant Mashrabiya-based proposal uses additive manufacturing or 3D printing to substitute the intensive tooling needed and to free the design from any milling constraints. Their final sand product for public space usage was a three-dimensional interpretation of Mashrabiya latticework design. The Microclimates project to be printed by the D-shape Company is to be built from clay with a complex internal structure whose large internal surface area is claimed to efficiently condition the air passing through it using an evaporative cooling characteristic, when water is fed from above to this porous sand structure.

The Microclimates proposal bridges the gap between a tool-free Mashrabiya and that of an architectural and cultural product that can respond to a user's intentions and design preferences; see Figure 2-42. Although Postler and Ferguson have hinted at AM Mashrabiya it has never been done before or researched. This research aims to contribute to the knowledge of looking at the affordability and design validity of AM-produced Mashrabiya. A more advanced thought will also explore the possibility of importing the technology to be used with local materials, as encouraged by Fathy (1986). This knowledge is not only promoting a cheaper manufacturing technology but a sustainable one as well.

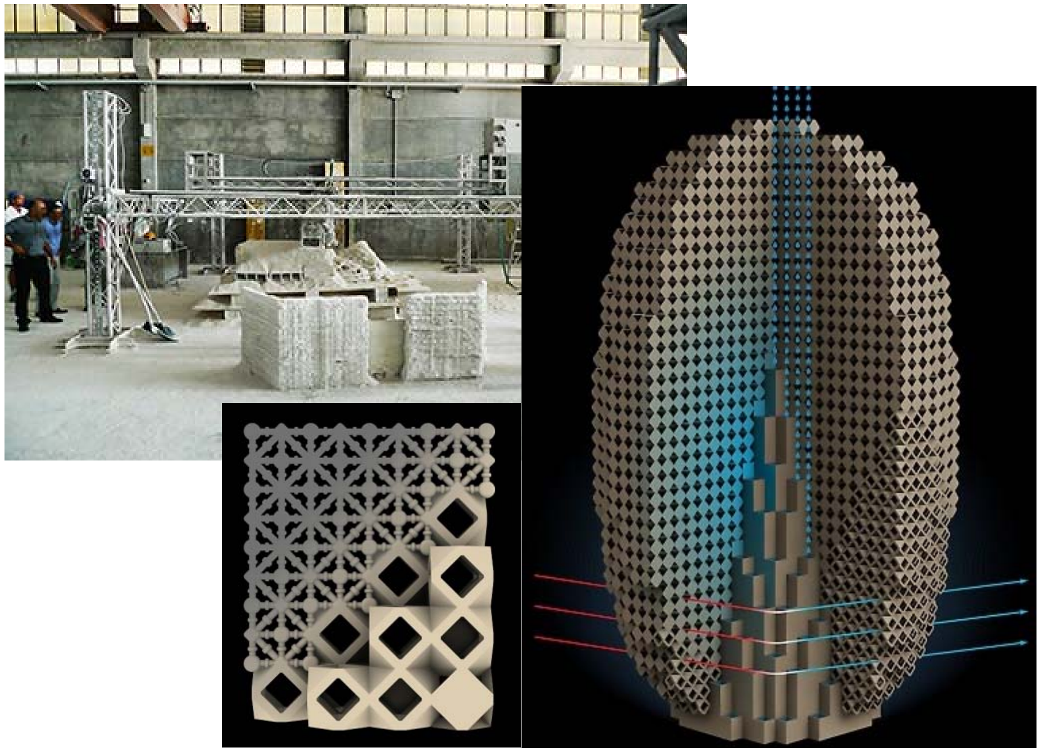


Figure 2-42: The giant 6m bed D-shape printer (left) and the microclimates (right). Source: Postler and Ferguson.com

THEORETICAL CONTEXT, GLOBALISATION, SUSTAINIBILITY AND THE VERNACULAR

The previous sections of this research comprehensively documented the definition, materiality and manufacturing of Mashrabiya. Looking at the Bahraini type of Mashrabiya as a context case study can provide a better understanding of the subject. Documenting what is already known about Mashrabiya was followed by an analysis of the current trends of Mashrabiya manufacture and its development concepts. Innovative ideas and designs were also examined, from static to virtual models to real-scale projects. This section discusses the theoretical contexts of Mashrabiya between its heritage conservation domain and current architectural practices. The section also explains the theories surrounding its innovation with reference to the sustainability trend and the renovation of its vernacular characteristic in a modern setting.

The theoretical context that best describes Mashrabiya as a product can be triangulated in the literature to contain religious, identity and sustainability contexts, see Figure 2-43. Understanding each of these theoretical context background areas can give a better understanding of the research product. Both Sidawi (2014) and Aljawder (2014) gave a documented explanation of Mashrabiya as a product of religion. Abdelsalam and Rihan (2013) looked into Mashrabiya as source of identity and trend. The sustainable context is evident in Mashrabiya vernacularism, materiality and its traditional and new functions. However, the practices of architects and designer give more emphasis to the traditional Islamic ideology and stylistic authenticity and appearance of Mashrabiya.

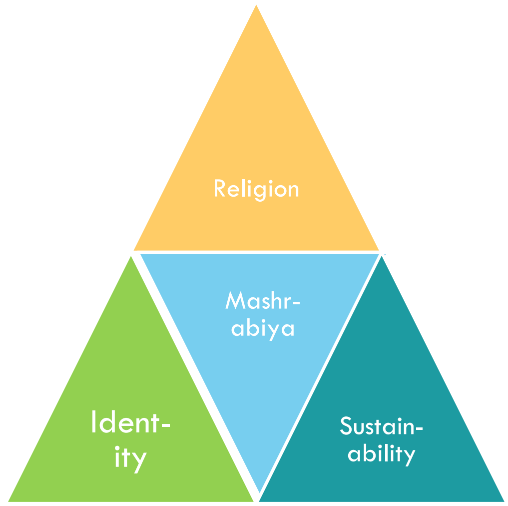


Figure 2-43: * Triangulation of Mashrabiya theoretical contexts. Source: Author contribution.

While Hui (2005) stresses the importance of a framework of social and environmental awareness of Mashrabiya as a sustainable solution, Yousuf (2011) gives a more detailed understanding of the subject. In Yousuf's argument he relates the development of sustainability to economic, environmental and social sustainability. He also highlights a few challenges that slow the development of sustainability initiatives among Middle Eastern countries, as illustrated in Figure 2-44. All the challenges mentioned can be reflected in the development of a new Mashrabiya, as will be discussed in the coming section. For example, the economics of the initial cost of any new sustainable product may be high at the beginning but the running costs and lifecycle can compensate for it in the long run.

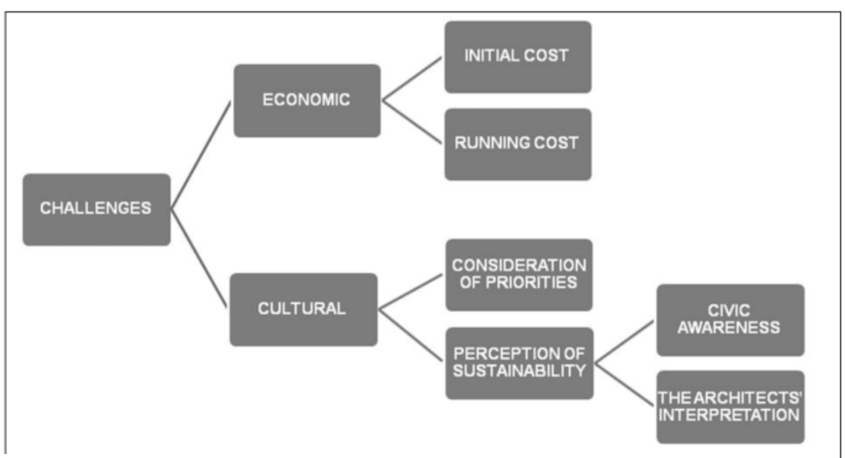


Figure 2-44: Challenges of sustainable architecture. Source: Yousuf (2011).

Nevertheless, a new trend of globalisation noted by Dayaratne and Karajica (2007) and Dayaratne (2008) alludes to a more general theoretical context that supports Yousuf's (2011) sustainability context. Their argument is based on two theoretical approaches, vernacularism and global urbanism. Vernacularism is the trend of reconstructing the past image of vernacular architecture through modern forms to follow traditional vernacular functions. Dayaratne (2008) noticed that people have found an amenable way to reconstruct their links to the past. The government also played a role in this by reviving and re-imaging the past through housing projects or public buildings where traditional images are mixed with modern trends.

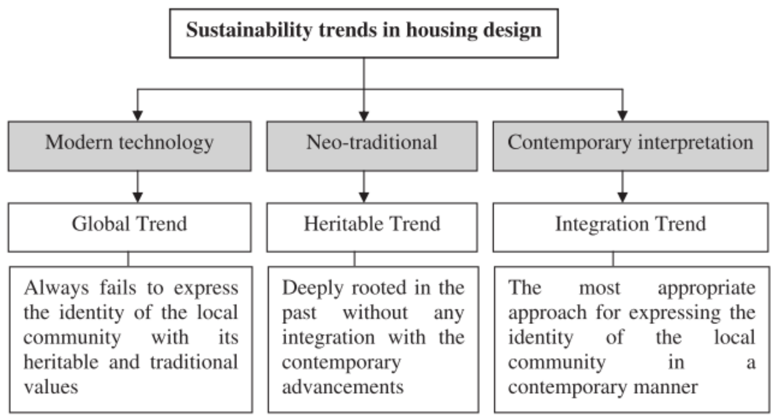


Figure 2-45: The impact of sustainability trends on Arab city identity and heritage. Source: Abdelsalam and Rihan (2013, p171)

There have been some claims that most of the post-modern revivalist movements have emphasised the importance of the stylistic appearance and have noted the typologies of historical architecture and its elements such as Mashrabiya. Other claims discussed in this section have argued that architects should think '*glocally*', which Eldemery (2009) explains is a composite term describing the need to look back to the local from architects' global position. Others sought to find a new way to revive historical architecture, such as Abdulsalam and Rihan's (2013) research conclusion shown in Figure 2-45. In conclusion, the need to shed light on sustainable trends that represent heritage using hybrid technologies in architecture is vital. This supports Fathy (1973, p. 128), who stated:

> "*there must be neither fake tradition nor faked modernity, but an architecture that will be a visible and permanent expression of a community*".

2.4 3D PRINTING FOR ARCHITECTURE TO SUBSTITUTE THE CRAFTSMEN

The previous sections explained the importance of Islamic architecture and the values dominating its buildings and culture. It also mapped an accelerating growth of modern architecture in Muslim countries like Bahrain. Taking Mashrabiya as a product interwoven in culture, craft and the sustainable architecture environment was of high importance. The new trends of reproducing Mashrabiya were also previously explained in detail in section 2.3.7–2.3.10. New technologies and manufacturing methods also played a role in the development of Mashrabiya, like the 3D-printed Microclimates concept and the cool brick 3D-printed product. The current significant manufacturing technology known as additive manufacturing and 3D printing can be part of the Mashrabiya development in innovative design process as a new production possibility.

But what is 3D printing exactly, and how does it differ from subtractive manufacturing? Is 3D printing as a new manufacturing technology capable of producing products of an architecture scale? How much would that cost and what are the economic constraints governing it? How can this technology be used to bridge the gap between the digital CAD design models of new innovative Mashrabiya and the 3D printing manufacturing material? Most importantly, what are the potentials of parametric modelling if combined with culturally meaningful functions such as that of a Mashrabiya? Precisely, what is the potential of what can be 3D-printed over that manufactured conventionally?

This section tries to answer these previous questions from projects and data found in the literature and scholarly articles as well as manufacturing market reviews. The section also covers 3D printing or additive manufacturing in general and 3D printing for architecture in particular. This triangulates Mashrabiya as a resulting product that spans between architectural facades, the interior environment, craft and manufacturing capabilities, as well as product innovation disciplines.

2.4.1 Additive Manufacturing (AM) and 3D printing

The term additive manufacturing (AM) is adopted to describe a wide range of digital 'layer by layer' fabrication techniques. The American Society for Testing and Materials (ASTM) defines AM as the process of producing a three-dimensional solid object using a CAD digital file to produce any shape (Wohlers, 2014). The concept of additive fabrication first emerged in 1987 with stereolithography (SL) from 3D Systems. Unlike subtractive processes such as milling or drilling and formative process like forging or casting, or joining process like fastening and welding, additive manufacturing has its own processing abilities (Conner et al., 2014). AM can be used to produce tooling as well as fixturing of conventional manufacturing processes. Using AM for these processes is claimed to be more affordable and faster than conventional manufacturing.

Strauss (2013) explains that 'additive fabrication' includes a family of additive methods as seen in the following chart. The terms include 'Rapid tooling', 'Rapid manufacturing' and 'Rapid prototyping'. The term '3D printing' falls under 'Rapid prototyping' and is defined by ASTM as the process of fabricating objects through depositing a material using a nozzle, print head or other printer technology. Nevertheless, the term '3D printing' is used as a synonym to 'additive manufacturing'.

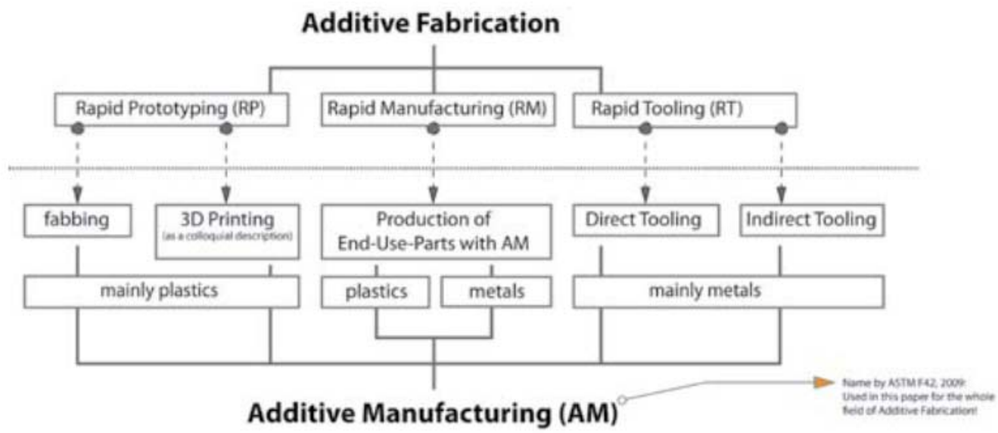


Figure 2-46: Additive fabrication terms. Source: Strauss (2013).

According to ISO and ASTM, Wohlers (2014) indicated that additive manufacturing is the official term of the industry but the term '3D printing' has become more popular than AM. Wohlers (2012) reported that the investment community, mainstream press and CAD industry use '3D printing' when referring to AM technology and the industry it represents. As a result, educators, bloggers and others adopted the term widely. On 16 October 2015, a Google search by the author produced 5 million results when entering the term 'additive manufacturing'. The term '3D printing' produced 90.7 million results. Therefore, in this text the term '3D printing' will be used as a synonym for additive methods.

Berman (2012) explains that 3D printers work in a similar manner to inkjet or traditional laser printers. Instead of using multi-coloured inks a 3D printer uses powder material that is slowly built into image thin cross-sectional layers of a 3D CAD model or product. Another 3DP technologies machine dispenses a thin layer of a liquid resin. An ultraviolet (UV) laser then hardens each layer in a repeated manner.

Stereolithography was the first 3D-printing technology invented in 1987 to produce visual prototypes used in design and marketing stages. In 1991, three new additive technologies emerged, including Laminated Object Manufacturing (LOM), Fused Deposition Modelling (FDM) and Solid ground Curing (SGC) (Wohlers, 2008). Later, Selective Laser Sintering (SLS) became available in 1992. As Conner et al. (2014) asserts, each of these technologies has its own potential impact on processing capabilities, build volume, product quality, speed, materials and advantages and limitations.

Year after year, rapid growth accelerated this industry not just in the AM technology used but in the materials and bed size as well as the time consumed. A detailed timeline and innovation growth can be traced through the past 20 editions of Wohlers Reports by Terry Wohlers and his associates. Wohlers Reports not only document the trends and history of AM but give reliable industrial segments and future forecasts of possible opportunities and AM industry growth.

Although the industry is currently used to manufacture mock-ups and prototypes, a good number of promising applications exists. End-use products as artificial limbs, dental crowns and replacement parts are good examples. Hague (2006) notes that the main benefit of such manufacturing technology is its ability to manufacture parts of virtually any geometry or complexity without the reliance on tooling.

2.4.2 3D printing versus subtractive manufacturing

It is not yet possible to claim that 3D printing as a manufacturing technology will replace subtractive manufacturing. However, a vital understanding of the potentials of 3D printing against that of subtractive tooling will clarify this argument. Subtractive tools dominate the market today, such as milling and CNC machining. But the fact that 3D printing has moved from having prototyping capabilities to be a high-value 'end user' customisation tool as noted by Soar and Andreen (2012) makes it a subject worth investigating and forecasting. The reliance on the fact that additive manufacturing and 3D printing being are just additive processes rather than subtractive ones illuminates the need to consume time assembling existing parts. Instead, an additive process disregards the need for tooling, as noted by Hague (2006), Lim et al. (2012) and Strauss (2013). This can also mean that many of the restrictions of 'Design for Manufacture and Assembly' (DFMA) are no longer valid, as noted by Hague (2006).

Berman (2012) also asserts that 3D printing has a cost effectiveness value and speed if compared to injection moulded processes. 3D printing can allow savings on the costly moulds, as well as a possible recycling of about 95%–98% of waste material if metal or powder is used. The nature of the manufacturing allows the ability to economically build custom products over a limited period of time. Also, an advantage of sharing the design and upgrading it to new potentials and forms is theoretically limitless.

Conner et al. (2014) highlight even more advantages in form generation using 3D printing. They claim that using complex parts to enhance visual appeal or performance are now a granted possibility. Product features like deep channels and wall thickness are much easier to control in their virtual models if tooling was not used. Since the tooling cost would be reduced, and the associated time needed to produce tooling is dispensed with, as well as their storage and maintenance, AM and 3D printing could therefore shorten the time in which a product reaches the market, as reported by Wohlers (2014). This option may also modify production rates to match rapid market demands.

In reality, experts agree that 3D printing (3DP) may not be advantageous for an entire product, but can be for individual product parts. This is especially the case if consolidation, light weighting and lattice structure design were implemented. Consolidation is the process of redesigning a product to take advantage of the complex assemblies and shapes AM and 3D printing offers. The process defined by Wohler (2012) includes reducing the number of parts in an assembly. This can be advantageous also in reducing the cost of overheads related to design documentation and product production control and planning. The low number of resulting parts can also mean a reduction of labour and time used for assembling the parts. A future hope relies on consolidation causing a smaller 'footprint' that may further cut costs and sustain resources (Berman, 2012).

Weight reduction, on the other hand, is a more conventional AM advantage found in Aerospace industries as a successful example. Optimisation of a product typology can also be validated when the thickness of low stress parts is reduced. Another form of lightweighting occurs when the exterior form of a product part is maintained for functional and aesthetic purposes while the interior uses a lattice mesh structure instead of solid materials. This optimisation and lattice structuring of a product can balance the use of material around areas that require strength to those which do not (Wohlers, 2014). Reflection on architecture products and its structure can help to integrate both complex forms and functions without additional work expenditure, as claimed by Strauss (2013).

Whether the parts are produced for medical hearing aids or architectural facades, Soar and Andreen (2012) as well as Wohlers (2014) agree that AM and 3D printing has moved from being a prototyping industry to an 'end user' one, penetrating many niche markets. However, the shift from mass manufacturing to mass customisation within these markets is more dependent on overcoming the challenges that are preventing this technology from being the 'next industrial revolution', as many researchers claim. In particular, 3D printing and AM machines suitable for end-use production are still expensive (Wohlers, 2008–2014). And this is also the case with its materials and relative speed and throughput, as will be explained later in this research section.

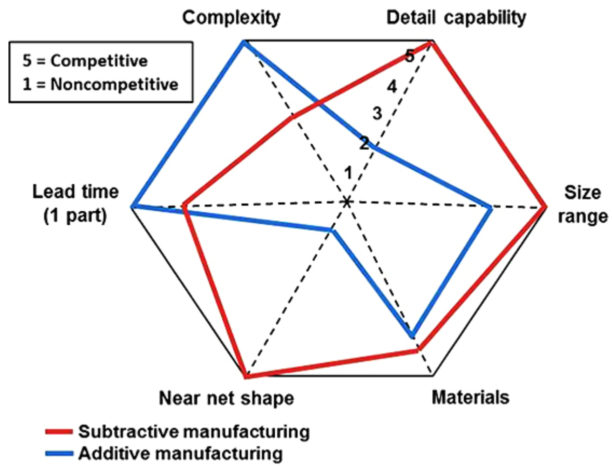


Figure 2-47: Additive manufacturing versus subtractive manufacturing.

Source: http://chronicle.kennametal.com/wp-content/uploads/2015/03/3DFigure_top.jpg

2.4.3 Designing for 3D printing: Potentials and drawbacks

The rapid growth of 3D-printing manufacturing technologies not only affected the end product cycle but also affected the pedagogy of product design itself and its practice (Ford and Dean, 2013). In the 1980s the shift from manual to 2D CAD drawings took place, relying on highly priced systems. About 10 years after, realistic renderings and visualisation using CAD software diverted the value of the form of designed pieces to their aesthetic animated character. Ford and Dean (2013) argue that a true understanding of the design potentials and drawbacks of 3D printing capabilities is needed before delving into the technology as a norm in the practice of product design. Therefore, the next part of this text will explain more about the positives, negatives and restrictions while designing for 3D printing as well as providing an overview of its possible applications.

The main driver behind the rapid growth of 3D printing and manufacturing is its positive potentials, as suggested by Hague (2006). He claims that this technology can offer different design methodologies. It is not only the case that design methodologies can change but a new dimension of 'Manufacture for Design' rather than the conventional 'Design for Manufacture' can emerge. This is due to the ability to produce complex freeform geometry using three-dimensional modelling software without thinking of the tooling required. Both customers and manufacturers can benefit from the speedy release of products. Moreover, Ponche (2012) and Berger (2013) argue that a functional product part can be generated directly from its CAD model. Berger (2013) pledges that such processes can increase productivity as well as enable a cost and mass reduction and an increased growth of product functionality.

Although 3D printing offers all these previously mentioned potentials, Wohler (2010, p. 34) states that "the most significant barrier to realizing new application and powerful benefits is our reluctance to change". Soar and Andreen (2012) support this change or compensate for a joint process of CNC subtractive and formative processes with 3D printing within mass market sectors. The resulting competitive advantage can highly influence and change the design market. There has been an increase in designing for customisation and design flexibility as well as material utilisation with complex geometry and functionality in fields such as engineering (Soar and Andreen, 2012).

Not only can 3D printing change the way we think and approach design but it can also make many designers and non-designers into 'makers'. Wohlers (2010) and Lipson and Kurman (2013) state that this technology can promote a new 'Maker movement' by adopting the same mentality as a do-it-yourself (DIY) school of thinking. Makers tend to blend technology to their will. It is evident that the maker movement has increasingly attracted enthusiastic people that crave for tools for production. These kinds of people might have their own CNC routers and 3D self-assembled printers in their basement. The emergence of this movement, Lipson and Kurman (2013) argue, means that profit may not be a core incentive to its participants. The fact that Makers may not behold a massive supply chain nor thousands of employees makes them more creative and playful in their design experiments.

The grouping of the 'Maker' skills and the '3D designers' skills lacks the influence of the digital craftsman artisan skills. The digital craftsman can be defined as an artist or designer who relies on advanced computer software and algorithm programs to sculpt his objects or manufactured designs pieces. The emotional attachment and tool-less manufacturing flexibility can allow new personal approaches to product production and mass customisation, as endorsed by Ford and Dean (2013). The work of Zoran (2013) in his hybrid basketry gives an excellent example of how a manual craft can be upgraded to a new form and dimension. Another related example is the concept of the digital tectonic (building form and construction) by Beesley and Seebohm (2000) that has become a powerful agent in reconciling traditional and contemporary manufacturing via 3D printing. Linking the maker, designer and digital craftsmen can highly advance the design potential of 3D printing.

Nevertheless, the drawbacks of 3D printing are defined by Campbell et al. (2012) and Berman (2013). It is constrained firstly by production speed and system cost, accuracy and nonlinearity appearing in the different XYZ resolutions and wall thicknesses. Secondly, the material colours, choices and selection of surface finishes and options are also limited in this industry compared to those available in mass production. It is valid here to note that a serious problem with products designed for 3D printing relates to implications of intellectual property (IP) security. Berman (2012) justifies his concern by relating to the actual fact of the objects being described digitally. This can mean they can be copied and resold easily. Product clones can effortlessly be printed once the blueprints of a product are uploaded to a website. While research is rapidly growing in the field of 3D printing, materials from examples of sand, to wood and even salt as proposed by the Emerging Objects Company are developing every day. On the other hand, the IP issue is a political and governmental concern that needs new investigations and awareness.

The huge media coverage and hype around the technology itself is slowly attracting attention towards its real application benefits. 3D printing is widely used in low production applications, complex designs and small-sized parts. These factors also determine the technical possibilities and economic feasibility of a 3D application design, as suggested by Berman (2012). Valid applications of 3D printing can be seen in the aerospace, automotive, military, and medical and consumer goods sectors. Jewellery, furniture and even shoe designs are emerging sectors as well. Initially it was a method of producing a prototype object and then it shifted towards producing tooling and moulds but eventually it turned to producing 'end user' parts. 3D-printing products can range from as thin as silicon chips on a nanometre scale to that of pods and partitions of above one cubic metre, as seen in the Freeform company architecture construction (Soar and Andreen, 2012). Strauss (2013) positively assures that the development of large-scale 3D-printing processes will change the way architects design and produce forms, alongside the way we design personal goods and even our built environment.

3D printing (3DP) design applications hold an alluring vision for future products that can be customised and respond to clients' tastes or 'lives' in a digital world. Both customisation and individualisation are key aspects of 3D printed products. Customisation refers to the tailiroing process of creating a product for the client needs and wishes (Piller, 2010). While individualisation is a form of product customisation but it is distinguished for creating products by the client wishes and desires in an automated predefined parametric process, (Campbell et al., 2013).

The work of Dean (2006) is an example that combines the skills of computational design and mass individualisation. Using rapid manufacturing and genetic algorithms as well as parametric CAD he designed several rapidly manufactured pieces of one-off artefacts. The Icon pendant piece is described by Atkinson and Dean (2008) as an attempt to prove the individualisation concept of an object on an industrial scale (see Figure 2-48). Icon was designed to mutate and provide a different piece every time the algorithm is run. The item would change the inner form while maintaining a coherent identifiable Meta design. This form of design and 3DP production has the potential to create new roles for the Maker, designer, user and computer software. This innovative role can influence not only the local design spectrum but global 3DP market trends.

Figure 2-48: Icon by Future Factories. Source: Atkinson and Dean (2008).

The revolutionary factor here is the participation via technology that has made almost everything possible in design. It has created a demand and a market that is easily accessed and connected worldwide. Soft or solid goods or products are being configured to customers' preferences. The technology language and tools today can be used by a wide range of people and are not restricted to specialists anymore. Holbrook (2013, p. 8) states:

> *"the personal computer, the printer and the internet made us all publishers. Now with 3D printers, 3D scanners and 3D design software, we can all be manufacturers."*

2.4.4 3D printing global market and the Middle East

During the past 26-year history of 3D printing an accelerated growth has been confirmed by Wohlers (2014) due to an increasing number of organisations adopting this technology. The compound annual growth rate (CAGR) of 3DP worldwide revenues was as impressive as 27% in 2014. The CAGR for the years 2011–2013 was 32.3%, as seen in Figure 2-49. Wohlers (2012) explains how service providers rebounded strongly in 2010 and 2011 after a harsh 2009 that had a low revenue. The year 2013 had a very strong product revenue compared to a lower services revenue. It is important to note that the additive manufacturing and 3D-printing industries have increased their growth to double digits in the last 17 years of their 26-year history (Wohlers, 2014). The market for this technology was $3.07 billion in 2013 while it was an estimates $2,275 billion back in 2012. See Figure 2-49.

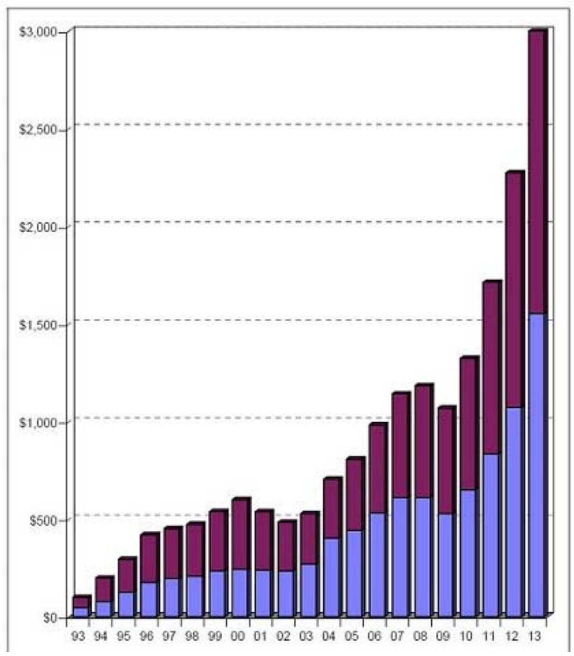


Figure 2-49: 3DP products (blue) to services (burgundy) revenue segments (in millions of dollars). Source: Wohlers (2014).

Lipson and Kurman (2013) question the rise of some technology compared to others which join our lives in silence. They claim that the burst of innovation happening with an emerging technology like 3D printing is due to its ability to remove the barriers of cost, time and distance. This has been endorsed worldwide. An estimation of the global economy by Wohlers' (2014) latest report indicates it to worth about $70 trillion. About 15% of this economy is dedicated to manufacturing. A future forecast estimates AM and 3DP to capture about 2% of this global market with its products and services. This estimation by Wohlers Associates is expected to rise in 2016 to exceed $7 billion worldwide, if not affected by an economic recession or natural disasters. The numbers generated in the past 20 years of the technology history only reached $1 billion while the amount has been doubled in the last 5 years. Such a growth rate and revenue does not only attract foreign investment but also accelerates research and creative applications in the industry. Lim et al. (2012) position 3DP and AM as an integral part of current product development, not just the home application that it has been marketed as.

Now with 3D printers, 3D scanners and 3D design software, we can all be manufacturers". However, designing for 3D printing is not as easy as it sounds. While software and online apps and platforms can make a few things look easier than they actually are, a real understanding of the technology needs specialists' input during the steps from design to manufacture; this applies even for the production of the smallest parts.

Therefore, Electrobloom (2013) highlighted the need to redefine development and manufacturing. 3D printing has a short development cycle, and allows for the manufacturer to make one or thousands of a certain object at the same cost. There is the further advantage of customising before making and the flexibility of modifying or moving parts without the need for assembly is fascinating. Communities can start their own factories according to their own interests and a new industry for localised production centres can emerge, making small businesses flourish easily and globally.

A wide range of global markets are receiving 3DP positively worldwide. The authentic experience of consumers using a 3DP product is a distinguishing feature. It has the potential to satisfy diverse as well as evolving needs. The fact that 3D prints are made to order and built from scratch to satisfy a certain demand raises its potential to adjust to consumption in the long run. For artists and craftsmen, 3D printing can unleash creativity and enable them to make what they can imagine. Composing both seemingly impossible objects and new materials as well as scanned objects opens up a new set of data markets. Thus, it can touch all industries due to the increase in its material range.

Brooke (2013) conducted a promising comparison of the 3DP market in the Middle East to that around the globe. She notes that the financial global crises that affected both UK and US markets increased investments in rich oil countries in the Middle East. This allowed them to take advantage of their opportunities regarding the race to achieving effective 3D printing on a large scale.

According to the market research firm Gartner, when the Middle East is compared to the rest of the world, it seems that adoption rates among businesses were on balance with Europe and Asia in 2012 at around 10%. This is a similar uptake to the 2011 figures and indicates firms' demand for the 3D-printing technology. Nevertheless, the US remains the biggest 3D-printing investor, as adoption rates were at 15% last year in the world's number one economy. Compared to the 2009 figures, Brooke (2013) notes that 3D printing is flourishing in the field of customised manufacturing. Keeley (2013) supports this prediction. He notes that the GCC region has opportunities for industrial production that do not require the traditional mass production factory setup.

Leading the way in the GCC are companies in the UAE and Saudi Arabia that have already started locally manufacturing goods, industrial machinery, and moulds. The advantages of 3DP in making savings in expensive tooling costs, imported materials and transportation make local goods production an attractive option for the GCC (Keeley, 2013). This may mean that 3DP has a bright future in that region.

More advantages are being harnessed by product developers and designers in the Middle East, as designers can benefit from 3D printing their conceptual products for testing and development. Upon approval, products can be sent elsewhere worldwide to be manufactured subtractively or additively. This will save them time and help them to be more innovative and create suitable products for local market demands. The unique character that distinguishes 3DP, especially in GCC countries, is its capabilities to create internal part geometrics that are nearly impossible to manufacture using traditional tooling. With the vast number of materials available and the reasonable, somewhat affordable, pricing, it can be said that the GCC is heading to a bright 3DP-based production future. This future could be a reality after the oil revenues decrease.

The Middle East and the GCC countries in particular like Bahrain, Qatar and the UAE benefit from several key economic drivers. Hvidt (2013) counts these drivers as, firstly, the government-led development followed by a fast decision-making strategy to allow 'fast-track' development. Another driver is the flexible labour force being imported from outside the GCC with different expertise and wages. Moreover, the market positioning via branding can support international partnering which can highly influence 3DP adoption. However, the economics of these countries are relying heavily on a 'supply-generated demand'; this could open the door for only viable manufacturing and valid production techniques, which could be an obstacle to developing 3DP. In Bahrain, for example, the production sector benefits from subsidised prices on land, electricity and water etc. In addition, oil and gas are often supplemented as feedstock to petrochemical industries at lower prices (Hvidt, 2013).

By arguing in favour of the global economic growth of 3DP and the reality of GCC and the Middle East potentials of employing 3DP in their manufacturing and production, a question arises. Would 3DP be of use for economies of virtually no domestic production like GCC countries that are used to exporting gas and oil and importing all other materials? Would the design and education industry support 3DP development in fields like medicine, consumer goods and architecture? And would it all be affordable and doable?

2.4.5 3D-printed product economics

The AM and 3D printing value chain consists of five elements, described by Berger (2013) as material, system, software, applications design and production. The cost and value of each of these elements depends on many other factors related to development and innovation growth. Conner et al. (2014) identify other key attributes of manufacturing to build a reference system to 3DP. Their three attributes are production volume, customisation and complexity. Rayna (2013) asserts that the economics of 3D printing will have a bright future as the technology develops and the costs will drop down eventually (see Figure 2-50). He based his forecasts not only on manufacturing reports but on economic facts and predictions of adoption trends. He argues that although few consumers own 3D printers, the 3D printers as a technology have already left the factories and reached offices. It can be anticipated that they soon reach homes as well-known companies are supporting this technology.

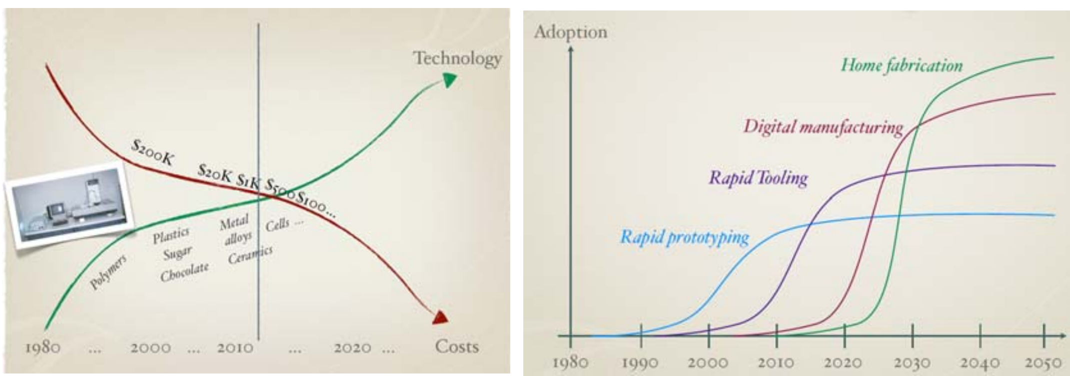


Figure 2-50: Thierry Rayna's 3DP economic forecasts. 3DP technology vs cost (left). 3DP adoption rate growth (right). Source: Rayna (2013).

3D-printing economics depends on two types of systems, industrial and commercial. Industrial Am and 3DP systems are those that cost more than $5,000. For a professional industrial 3DP system, the average selling price (ASP) was $90,370 in 2013 compared to $73,800 in 2011 (Wohlers, 2014). Wohlers also estimates a decline in the prices of systems and models that have been introduced in earlier years. The general increase in the ASP of industrial systems can be sourced to the rapid selling of metal AM and 3DP systems. Wohlers (2014) justifies the ASA sharp increase after 2010 to the fact that many machines at the low end of 3DP industrial systems are facing less sales due to the growing popularity of personal 3D printers. Berger (2013) earlier provided a general view of the 3DP economic landscape and argued that cost estimation usually assumes a maximum utilisation of capacity.

The other reality is that costs are highly dependent on the object geometry and material selected as well as chamber utilisation. The cost of 3DP is not an issue that can be entirely explained in this research context. However, an investigation into the fields advised by Berger (2013) is important within a specific scale or chamber size (see Figure 2-51). A more elaborate cost calculation related to rapid manufacturing was established by Ruffo, Tuck and Haque (2006). Their interpretations were based on both direct and indirect costs, seen in Table 2-4. The latter depended on quantitative principles and approaches to estimate cost using a new mathematical model for rapid manufacturing products of low and medium volume. These principles ranged between parametric models, where the cost is expressed as an analytical function with variables called cost-estimation relationships (CERs), and analogy-based techniques. Using the latter principle helps derive an estimation from actual information gained from similar products (Ruffo, Tuck and Haque, 2006). The CERs can be calculated according to the following equations adopted from Ruffo. ($Costb$) is the cost of a build using a sum of indirect cost combined with building time (tB). (mB) is the direct cost of material used while manufacturing.

$$Costb = Cost(tB) + Cost(mB)$$

$$Cost(mB) = \frac{direct-Cost}{mass-unit}\ mB$$

$$Cost(tB) = \frac{\sum indirect-Costs}{working-time} tB$$

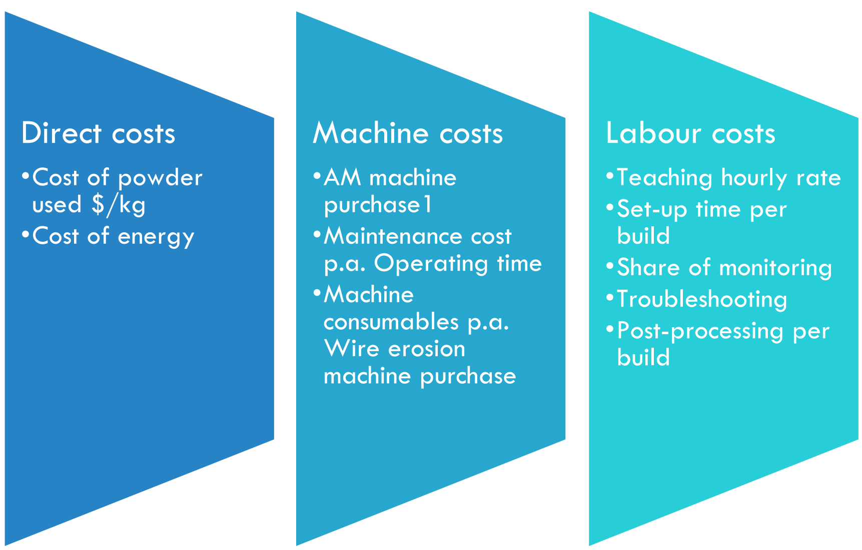


Figure 2-51: Based on Berger (2013).

Table 2-4: 3DP activities cost adapted from Ruffo, Tuck and Haque (2006).

Activity cost	Definition
Capital equipment depreciation	Depreciation cost of capital equipment (Machine).
Material	Cost of material purchase.
Hardware	PC purchase and upgrade cost.
Labour	Labour cost (annual salary) needed for machine setup and any required post-processing.
Maintenance	Capital equipment maintenance (costs per annum).
Production overhead	Costs incurred due to production, energy, and floor space.
Administration overhead	Costs incurred due to running the enterprise, office space, consumables and administrative staff.

Whereas the above-mentioned costs are valid for most industrial systems, a way of cutting the costs down could emerge through the dependence on cloud manufacturing (CM), as explained by Lipson and Kurman (2013). Wu et al. (2013, p. 2) define cloud manufacturing as:

> *"a customer-centric manufacturing mode that exploits on-demand access to a shared collection of diversified and distributed manufacturing resources to form temporary, reconfigurable production lines which enhance efficiency, reduce product lifecycle costs, and allow for optimal resources loading in response to variable-demand customer generated tasking."*

Lipson and Kurman (2013) see 3D printing as the 'catalyst' that CM has been waiting for. This is very true considering the fact that CM will be a decentralised system using ultra-large networks of average-scale businesses and companies. The internet and World Wide Web had once changed the telecommunications industry by connecting cell phones around the globe. CM and 3D-printing technologies is expected to do the same to the mass customisation industry. This can be done through the reliance on local 3D-printing services and products being delivered with the help of global designers and off-site services.

Rhyna, Petrick and Striukova (2013) document some long-term economic effects of this technology. While they argue in favour of the unleashing of innovation via 3D printing, they also predict massive cost savings on tooling, storage, transport and waste. A strong rise in the manufacturing industry would be based on regional and global development plans. By allowing competiveness and innovation, beneficial sustainable growth could positively impact all sectors involved in these future effects. The key argument here is that although growth is highly dependent on innovation, which is most frequently risky and costly, digital manufacturing can enable taking risk in producing new forms and unlimited shapes in a risk-free environment as assured by Rhyna, Petrick and

Striukova (2013). This can generate a new industrial revolution wave, causing radical changes in the economy. A reorganisation of the society and industrial sectors might be worth doing to control this economic growth and industrial shift. Despite the fact that this does not mean that mass production would end, it does, however, open the door to customisation. It should be kept in mind that customisation is only economical for small quantities, or for pieces that cannot be mass customised using mass production or relying on specific crafts.

In conclusion, the economics of 3DP is interwoven with a country's growing economic vision. Therefore, it is highly related to the role of governments. The way governments advise on new manufacturing technology adoption and how they steer and grow the ecosystem is also relevant. Rethinking and establishing new IP rules to control this technology is valid here. This is claimed to help build a trustworthy environment for the economic growth of digital manufacturing in any country. With Berman's (2013) forecasts of a drop in the raw material prices and an increase in material quality, the 3DP technology will go beyond its current scope. He also gives a 5-year estimation for the development of the 3DP supply chain, not just in design but production as well. By spreading CAD-CAM designs for general public download, individuals will be able to view a virtual library of designs to choose from. With the increased abilities of CAD-CAM applications, many non-competing professionals and companies may as well join the 3D-printing revolution to reduce their investment costs and follow the technological trends and hype. Applications in bridge manufacturing and architecture are finding their place within this hype, as stated by Soar and Andreen (2012) and Berman (2013).

2.4.6 3D printing on an architectural scale

3D Printing or Rapid Prototyping is a mature technology when it comes to low- and medium-scale production. Large-scale 3D printing, especially that of architecture and building-scale size, is considered to still be in its infancy. The 3DP materials usually used within the technology are intended for a short life expectancy and are non-performing structurally. Thus, they are meant for immediate analysis and evaluation of a prototype form, scale, fit, etc., as noted by Rael and Fratello (2011). Exceptions to this are emerging as parametric modelling and digital optimisation are becoming more integrated into the design process. Crolla and Williams (2014) from Smart Nodes note a strong example of how the technologies are enabling new modes of production and assembly in architecture. As noted by Crolla and Williams, this technology is not necessarily "new" but as its patents has begun to expire, the machines and the materials have become prolific and omnipresent. Headley et al. (2015) hypothesise that the cost of 3DP technology could potentially be lowered to the extent that additive manufacturing could compete with traditional manufacturing (Crolla and Williams, 2014).

The race in architecture that uses 3DP has been rapidly growing. From bridge construction to bricks and modular homes, the concept is raising innovative solutions every day. The Museum of the Future proposal in Dubai, UAE, is targeting its first office to be fully 3D printed by the Chinese Winsun Company. For the past ten years or so, the 3DP Winsun Design Engineering Company has promoted the 3D printing of homes as a 'Product' with other 3DP screens and walls (yhbm.com 2015). On the other hand, Brian Peters, in 2013, was capable of developing 3D printers that specialise in customised ceramic brick making. These bricks are parametrically optimised around ornamental and structural performance.

Figure 2-52: Winsun Design Engineering Company using Concrete 3DP homes technology. http://www.yhbm.com/index.php?m=content&c=index&a=lists&catid=67

Headley et al. (2015) and Dritsas and Yeo (2013) note question that arise in light of this revolution as notions of authorship become relevant and the cultural implications of potentially replacing construction labour appear in the future. Headley et al. (2015) argue that this technology has boundless potential to save historic architectural paradigms and construction types. Moreover, the claim of using a sustainable local material in the creation of these large-scale architectural elements promises better construction technology for the future, as seen in the following cases in Figure 2-52.

The restrictions to this technology within the field of architecture are associated with its scale and cost. Modeen cited in Celani (2007) states that the 3DP phenomenon is relatively recent in the design-related fields. The affordability of relatively expensive architecture mini models does not compensate for 3D printing real architecture and design parts. However, the leading research of Foster and Partners and Loughborough University, UK in this field is proving another possibility. Foster and Partners has a special modelling software and modelling suite that combines the 3D-printing process with CNC laser cutting tools. The fact that both 3D printing and architecture models rely on CAD software tools makes them very much connected if tooling is to be ignored. Another benefit is the use of Building Information Modeling (BMI), which can undoubtedly increase automated processes and manufacturing within the construction industry.

Research wise, Joseph Pegna in 1997 demonstrated a new construction method of layer-by-layer selective curing and consolidation of cement structures by steam, as cited in Soar and Andreen (2012). His technique was called Free-form Fabrication. In the year 2012, Lim et al. (2012), with the pioneering of research of scholars at Loughborough University, proved that AM in construction can begin to move forward. They describe three construction-scale 3DP processes used to manufacture large components. Their research bridges AM and 3DP, from being a modelling tool used by architects to a tool used to deliver full-scale architectural components. Their research has focused more on 'concrete printing' as an automated extrusion-based product. A clear comparison between Counter Crafting, Concrete Printing and the techniques of the D-shape Company was conducted and investigated within an architectural application.

Egg-shaped house (2009) by Andrea Morgante and D-shape	KamerMaker 3D-printed Canal House (2013) by DUS Architects	Micro apartment (2014) by UCLA architecture students, 3M futureLAB and Voxeljet	3D-printed housing complex by Chineese WinSun
Source: http://www.laurabielecki.com/	Source: http://media.columbian.com/	Source: http://www.designboom.com/architecture/3m-futurelab-3d-printed-house-by-ucla-hud-04-06-2014/	Source: http://www.yhbm.com/index.php?m=content&c=index&a=lists&catid=67

Figure 2-53: Examples of architectural-scale 3D-printed objects.

Practice-wise, in 2009, the Egg-shaped house of almost 3 metres in height was considered to be the first-ever printed architectural structure, as claimed by Dezeen.com (2013). The project was a collaboration between the architect Andrea Morgante and Enrico Dini (D-shape), owner of the largest 3D printer in the world at the time. When Dini built his structures out of sand and chemical binding agents, a revolution in architectural manufacturing started. However, a disadvantage of the structure was its long printing time, as it was printed in pieces and then assembled at a rate of 5cm per hour over a 30 square metre area and a depth of 2 metres. The form might not be sophisticated enough; however, the aesthetic concept and the idea of printing a layer-by-layer building out of sand proves that 3D printing is feasible on an architectural scale; see Figure 2-53.

The form developed into a bigger and more defined one using the KamerMaker 3D printer to build the Canal House by the end of 2013. The Dutch DUS Architects based in Amsterdam developed another giant 6-metre tall 3D printer. The KamerMaker is capable of printing building parts from Polypropylene of up to 2.2 by 2.2 by 3.5 metres in size, as documented by Holloway (2013). Using plant-oil based plastic, the layered structure was on display to the public for them to feel and touch the fine finish of this assembly. The question here is whether it is worthwhile to build printers as large as the houses themselves? Will these experimentations ever feasibly replace conventional manufacturing?

An answer to this question can be seen in another smaller accommodation type, where form and function meet in a practical way. The compact micro-apartment project documented in designboom.com (2014) claims of a mobile yet comfortable small-scale accommodation that was conceptualised into reality by UCLA architecture graduate students and Professor Peter Ebner, in collaboration with 3M futureLAB and the German 3D-printing company Voxeljet. A highly detailed space that includes built-in furniture, a screen and a sanitary system was printed in one go yet in two parts and resulted in an efficient 2.2 by 2.2 metre unit. The 3D-printing phase and assembly of printed parts can take time and add to transportation costs. However, WinSun in 2014 promoted the printing of ten houses over a period of 24 hours, speeding up the process and decreasing the production time by 50–70% as well as saving 50–80% of labour costs.

Notably, however, there is not yet an adequate form of technology to link a CAD design and a CAM process directly to the built environment, as concluded by Strauss (2013). This cannot remain the case for long as innovation into materials and technology is developing rapidly every day. It is foreseeable from the given examples and case studies within the last 18 years of AM development and within the architectural 'facade' envelope that AM and 3D printing can possibly change cladding and structures in the very near future. Examining these construction approaches and possible application within architectural building façades or components can be joined with the changes in architects' mentality and the use of BIM systems. This can lead to a new way of building and construction language if proper understanding of the technology is supported by experimental applications.

All the optimistic experimentation and views expressed here do not change the fact that 3DP for architecture should meet a few conditions first. Soar and Andreen (2012) require 3DP to come up with materials that can address future needs and be synthesised with local sources besides being indigenous to the production location. They would preferably be fully recyclable within their end of life location or within the factory environment. 3DP for architecture should have greater performance than simply freeform aesthetics alone. They conclude with a powerful statement:

> *"By removing the bottleneck between digital design and fabrication, both detail and non-standardization emerge which may well be classed as a 'digital vernacular'"* (Soar and Andreen, 2012, p. 128).

2.4.7 The concept of producing 3D-printed Mashrabiya: From parametric design to manufacturing possibilities

The first part of section 2.4 explained the definition of 3D printing and its capabilities as a manufacturing tool and a form of economic hype, while the last section focused on understanding the possibilities and limitations of using 3D printing for an architectural-scale production. This section integrates the knowledge of advancement in architectural-scale 3D printing with the previously explained Mashrabiya product. Since Mahsrabiya is a vernacular product that heavily relied on craftsmanship and culture, the following text investigates the concept behind reviving the Mashrabiya using the capabilities offered by digital design for tool-free 3D printing. The arguments and research documented here can be used as evidence for the earlier concept of the 'digital vernacular'.

The production of the 'digital vernacular' promoted by Soar and Andreen (2012) can be approached and proven valid through the link between digital fabrication and sustainable vernacular approaches. Design and manufacturing possibilities have bridged the gap between digital designing and crafting to respond to optimised thermal and heat characteristics. With the reliance on Building Information Modeling (BIM), CAD software has upgraded its aesthetic modelling capabilities to scientific ones. Zoran (2013) asserts that digital fabrication and especially parametric tools can transform the entire design landscape. Moreover, Zoran and Buechley (2013) pledge the preservation of important craft designs through the reliance on accessible CAD tools combined with 3D scanning and 3D printing. The work of Zoran (2013) is an excellent example of a restored vase design that preserves the features of craft and provides a new aesthetic dimension to it. The concept behind maintaining the original artefact yet blending this with a new restored extension is now possible using 3D scanning and 3D printing (Figure 2-54).

Figure 2-54: Amit Zoran's digitally restored pottery, 2010, using 3D scanning, CAD modelling and 3D printing. Source: Zoran (2013) cited in Almerbati and Headley (2016).

The capabilities of using 3D printing in reviving and conceptualising new products based on architectural archetypes has been noted by Dritsas and Yeo (2013). Their research highlights the

importance of finding digital methods for the 'undrawable architecture' realm. They define 'undrawable architecture' as a process of tacit tectonic knowledge that had been passed between generations. The elements of 'undrawable architecture' might have never been formalised and the complexity of their artisan craftsmanship may well be very difficult to reproduce and rationalise. The examples Dritsas and Yeo (2013) showcase constitute a collective approach to digital conservation through scanning and processing the data gathered in prototyping technology. The resulting material culture and craft conservation process can be named as 'virtual heritage'.
The digital hybrid concept of the traditional Tea House by Ko and Liotta (2011) can be considered as an earlier attempt of conserving 'virtual heritage'. This uses a combination of formal innovations arising from the design process and applies them to the concept and reconstruction of tea houses. The work relies on parametric design processes as a mechanism used by architects to construct new forms of a tea house. Their investigation looks into renewed conceptual meanings as well as the retention of the traditional architecture soul with its cultural values. Taking into consideration weather conditions as well as materiality experimentation and structural analysis was aided by parametric design. However, the drawback of this method is a possible distorted resulting form. Distorted and complex forms may at times neglect issues that relate to culture, society and the economy. For an in-depth reflection on Mashrabiya as a cultural conservation possibility, refer to Almerbati and Headley (2016).

The ability of parametric design to take into consideration environmental parameters like weather adaptability and cultural values can be exemplified by the Microclimates project. Microclimates can be considered as the first conceptual product that combines Mashrabiya, parametric design and large-scale 3D printing. It is a conceptual project of a pod based on the Mashrabiya passive ventilation characteristics. The concept was proposed by Postler and Ferguson in 2009 and is mentioned in section 2.3. The Microclimates project adopted a Grasshopper algorithm to transform an Islamic pattern into several standing 1–2-metre pods that are claimed to passively cool the nearby environment if supplied with water from above. Depending on the sand material supplied and printed by D-shape, the concept targeted hot and humid climates but was never built due to the possible high costs involved.

The second concept was recently promoted by Emerging Objects (2015) in their 'cool brick' product and wall assembly launched in April 2015. This used ceramics and a porous form to act as a cooling screen in arid climates. The designers Virginia San Fartello and Ronald Rael relied on parametric and modelling algorithms. Emerging Objects uses 3D printing to reconceptualise a thermal cooling brick based on the Mashrabiya concept or what they called 'Frescoes'. It involves creating a hollow brick to resemble the porous water jar, duplicating the concept of the 'ecooler' cooling screen tubes explained in section 2.2. The benefits of this product are its utilisation of the abilities of a digital craftsman or artist as a conscious scientist to design the form of the pieces and the ease of 3D printing as a mode of production. Unfortunately, this method may not be practical in GCC and Bahrain environmental and cultural context. As aesthetical appearance are highly important and environmental consideration is less appreciated on a residential level. Passive cooling through hollow bricks can also mean that air conditioning can escape the interior, and the holes might also be a great place of shelter for insects and humidity rot. It might need to be scientifically tested to prove its environmental efficiency.

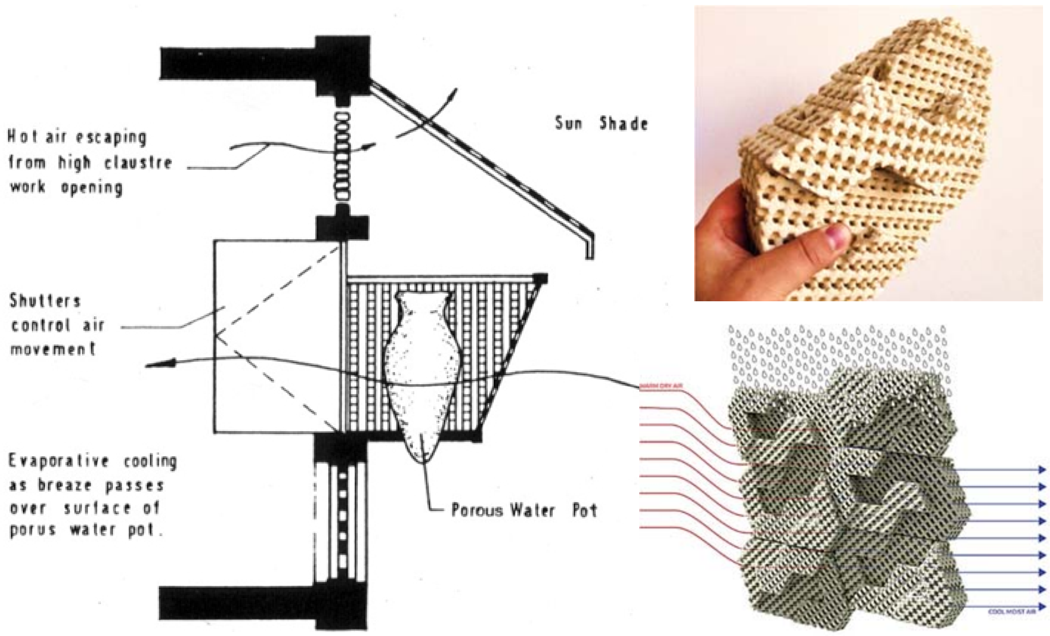


Figure 2-55: Cool Brick by Emerging Objects 2015. Source: http://www.emergingobjects.com/projects/cool-brick/

The heritage lessons arising from the example of the Mashrabiya concept should be well documented, studied and then carefully reproduced. Both the 'Microclimates' and the 'cool brick' cases relied on the environmental quality of Mashrabiya screens. They almost ignored the aesthetics and culture as well as the social domain Mashrabiya screens act within. A better understanding of the function, materiality and interaction of the Mashrabiya screen with its surrounding environment can be tracked down in the TRABASA workshop. This was a collaborative project in 2011 by a team led by Prof. Hisham Mortada at King Abdul Aziz University (KAU). According to Mayer and Styhler (2012) and Mortada and Joshi (2013), Alanwar House was chosen as a case to be studied as an example of the vernacular traditional building type due to its remarkable facade with its decorative projected balconies, Rawashen and Mashrabiya. Herbig et al. (2013) describe that the documentation covered three interwoven scales: the urban city, the local neighbourhood and the building's architecture. Among other details and architectural features documented from this survey, the window screens that have socio-cultural character and unique craftsmanship value were further studied and later archived, as seen in Mortada's (2014) research. Thermal indicators measured from the site combined with CAD models and Building Information Modeling (BIM) can help a better understanding to be reached of how these Rawashen functioned in the past and this can provide the seed for interesting future studies of their implementation in modern building facades and architecture within the MENA region. This work represents a substantial step forward in documenting regional architectures by using advanced technologies.

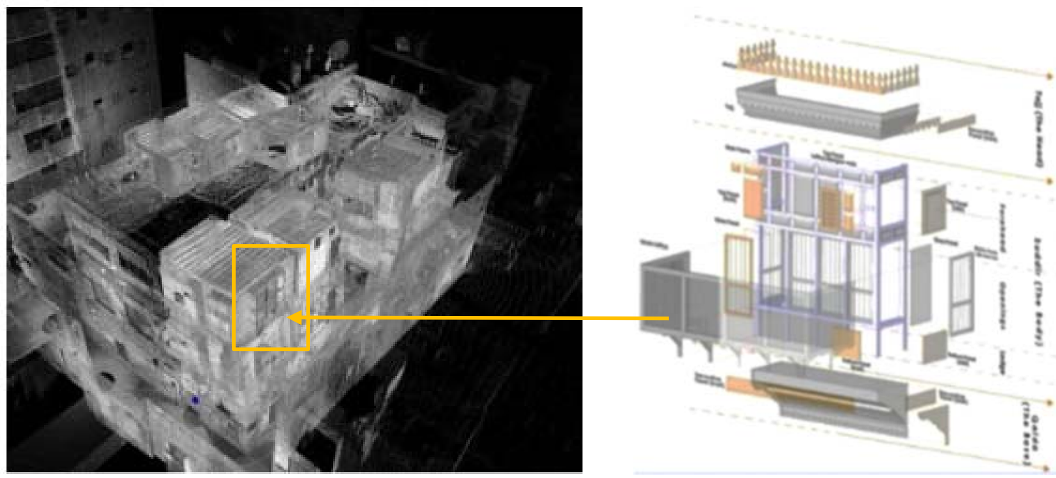


Figure 2-56 Left: A 3D point cloud scan of Alanwar House. Source: Mayer and Styhler-Aydin (2012). Right: A detailed study of Rawashen. Source: Mortada (2014).

Through the reliance on Mashrabiya virtual and scientific models and parametric possible designs, new objects and products may emerge. An object that closely resembles the social role of Mashrabiya can be seen in 3D-printed textiles as both serve a veiling role. "Transparency without a glazed medium" is how Kenzari and Elsheshtawy (2003) link the form of the Mashrabiya to that of an architectural veil, similar to Muslim women's body and head textile veil. Thus, Mashrabiya can have, as claimed, a social, political and a mystical form. Kenzari and Elsheshtawy (2003) consider the technique of creating holes and perforations in the solid wood as a necessary step to "reach the goal of stepping beyond the materiality of the screen". A parametric 3D-printed veil can also revolutionise the textile and fashion industry. From simple underwear objects to entire gowns made of assembled 3D objects, the possibilities are enormous (3ders.org, 2015).

Figure 2-57: Negar Kaltnar and Alireza Borhani from [trans]LAB's fixable textile. Source: 3ders.org (2015).

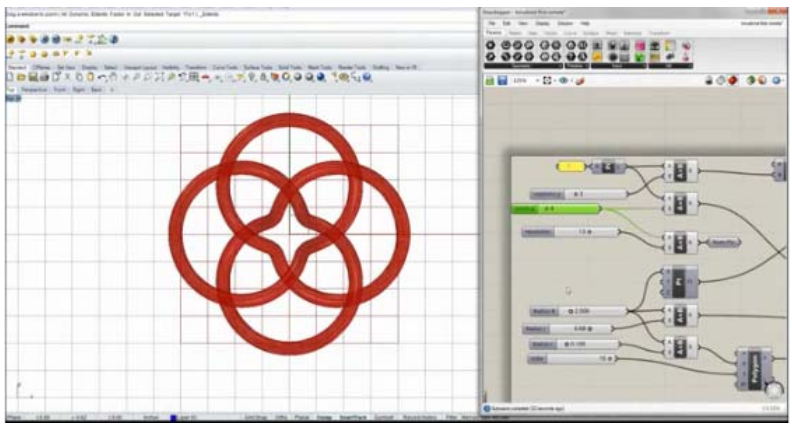


Figure 2-58: Parametric design of flexible motif textiles according to generated algorithm. Source: 3ders.org (2015).

In the light of the above discussion, structural complexity, the durability of materials, cost and surface quality are still concerns within most 3DP manufacturing streams. Research in ceramics and wood as well as other sustainable resources, like salt for 3D printing, is ongoing and promising in terms of overcoming materiality issues. Emerging objects material research is a good example here. It can be concluded that materials like salt and wood may be considered as sustainable green solutions in Middle Eastern countries. Along with salt that is available from the sea water desalination process, sand represents another local material that can be used for innovative manufacturing technologies like 3D printing. D-shape is one of the companies that is innovating in this field and other companies like Voxeljet and ExOne are following this revolution of sustainably producing 3D parametric products. Not only can 3DP produce sustainable objects but it can arguably be used to conserve architectural element like a Mashrabiya.

2.4.8 Concluding comments

This section provided information concerning the definition of 3D printing, its positives and negatives, as well as a comparison between 3D printing and subtractive manufacturing. Moreover, an analysis of the application of computational and parametric design potentials in 3D printing was provided here. The process of designing for 3D printing in general and architecture in particular was also investigated. Furthermore, the cost and economics of 3D printing as a manufacturing technology was summarised here.

This research section also focused on the cultivation of manufacturing innovation resulting from possible digital design processes. The obtained knowledge is argued to be applicable to the possible production of Mashrabiya using the 3D printing technology (3DPM). The discussion carried earlier conveys the fact that parametric design possibilities can be a mechanism through which designers and architects are able to produce new forms of Mashrabiya screens and revive its conceptual meanings. Thus, it can be a tool used to retain architecture that convergences with cultural values.

The growing market of 3D printing globally is slowly approaching the Middle East (ME) region market. The ME oil-income based market is slowly losing its financial support and the rise of new businesses and manufacturing industries is quite promising. With the rise of the Maker movement, developing countries like Bahrain may think of producing and exporting instead of importing all its goods. The possible benefits of 3D printing in refreshing the market and trade can benefit the region's economies.

It is important to highlight here that the aim of this chapter was to research the literature surrounding architectural-scale 3D printers in order to validate this technology for the production of Mashrabiya screens. In conclusion, the initial potential for the production of 3D printing Mashrabiya is relatively high and promising, as documented in the literature and in market reports. This section also provided background information for the research product in focus and indicated an economic, aesthetic and potential functionality that is worth looking at in more detail.

The notion of a 'digital vernacular' coined by Sour and Abardeen (2012) can be achieved through the 3DPM proposed here. However, this research does not promote only the end product but a set of values and design decisions that should be undertaken collectively to bring a 'digital vernacular Mashrabiya to life' in a conscious and economically wise way. Using digital craftsmen's tools and an artistic yet scientific approach via parametric design, a '21st-century hybrid arts and craft movement can emerge'.

2.5 CHAPTER CONCLUSION

This chapter has triangulated the literature from Islamic architecture and heritage values, Mashrabiya design and past products to examine current additive manufacturing possibilities in architecture. Thus, the content of Chapter 2 provides an understanding of the context, the product of interest and the targeted global and local manufacturing markets. The chapter provided fundamental knowledge and scholarly discussions about design guidelines that aid in the production of a new sustainable Mashrabiya. Moreover, this chapter explored the possibility of 3D printing as a possible Mashrabiya manufacturing process. The materiality of the proposed 3D printed Mashrabiya is a vital key in determining validity but it was not discussed here due to the developing nature of the technology and its material. This can be further researched in the future when the technology matures. However, a set of valid values that have always been associated with Mashrabiya should be analysed and developed after conducting this literature review.

The following questions have emerged after conducting the literature review and will be further investigated in Chapter 3 and triangulated to re-form a value framework:

- Within the social and cultural setting, how does the 3D-printed Mashrabiya (3DPM) design work respond appropriately to the values and mindsets of the urban context?
- How does the produced design fit into the fashion values and context of the given culture?
- What performative functions does the product achieve in the context of social/cultural, visual aesthetics, environmental/climatic, and emotional criteria?
- How feasible and sustainable is the production, transportation, assembly, and installation of Mashrabiya?

CHAPTER 3

***“You never change things by fighting the existing reality.
To change something, build a new model that makes the existing model obsolete.”***

Richard Buckminster Fuller

CHAPTER 3: RESEARCH FRAMEWORK

3.1 AN INTRODUCTION TO THE THEORY OF PRODUCT DESIGN VALUES

Savery and Duffy (2001) state that there is nothing that can be as practical as good theory. On the other hand, Gaffney and Anderson (1991) as cited in Savery and Duffy (2001) argue that there is nothing as interesting in theoretical understanding as good practice. The aim of this chapter is to understand the theoretical values behind Mashrabiya making as a design and production practice. This research further reflects on the manufacturing and design field. The chapter will also focus on product design in terms of the initial context of practice and its values compared to the general values of Mashrabiya traced in the literature.

It is necessary to compare the general design values of a Mashrabiya product as found in the literature. A triangulation of the values found in the theoretical literature and practice-based values is much needed, together with identifying the gaps that should be covered in new Mashrabiya design and manufacturing practices. The theoretical framework generated here will help to provide an understanding of the nature of the manufacturing of Mashrabiya and to accelerate its transformation from a conceptual model to a real-life solution.

The theoretical values of products in the design field may have been critically analysed by Veryzer (1995), Holbrook (1999), Crilly et al. (2004), Kumar (2008) and Biem and Jensen (2011). Looking into the subject from the point of view of consumer satisfaction, these scholars and many other researchers have investigated the impact that product value has on consumer preferences. Crilly et al. (2004) focused on the importance of the visual form of a product on consumer responses. In particular, they emphasised the semantic, aesthetic and symbolic aspects of a cognitive response to a particular design. Furthermore, special emphasis has been placed on the cultural, personal and situational factors that influence a product's design values.

The research by Kumar (2008) concluded that product design can encompass four main value types: social, altruistic, functional, and emotional. These value types are presented and defined in Table 3-1. Kumar named these values '*SAFE values*'. He then created a development process to help product designers embed these values in their products in order to obtain consumer satisfaction. The amount of value research in the product field is enormous and for the sake of clarity, specification and verification of several values under certain domains, Kumar (2008) will be further investigated here.

Table 3-1: Conceptual definitions of value in literature review summary by Kumar (2008) with modification. Source: Kumar (2008).

Construct	Conceptual definition	Source(s)
Value	Value is defined as an interactive, relativistic preference experience.	Holbrook (1999)
Social Value	The extent to which a product is able to achieve the status and esteem objectives of the consumer.	Created based on literature review (Holbrook, 1999; Boztepe, 2003)
Altruistic Value	Defined as the value the product provides in being right in the sense of being good.	Created based on literature review (Holbrook, 1999; Boztepe, 2003)
Functional Value	The extent to which a product helps achieve practical ends.	Created based on literature review (Holbrook, 1999; Boztepe, 2003)
Emotional Value	The benefits of a product in terms of the positive effect it provokes.	Created based on literature review (Holbrook, 1999; Boztepe, 2003)
Regulatory Constraints	The extent to which the product development was affected by limitations placed by the guidelines provided by government agencies.	Created based on literature review (e.g. Montoya-Weiss and Calantone, 1994)
Technology Constraints	Defined as the technological feasibility of the features specified by the market.	Created based on literature review (e.g. Slotnick and Sobel, 2002)
Resource Constraints	Defined as the constraints imposed by project development, production, R&D and marketing costs.	Montoya-Weiss and Calantone (1994)

Unlike other researchers, Kumar (2008) was able to validate his SAFE values by examining the created objects of several product designers. He was able to demonstrate an understanding of the interwoven factors of consumer expectations and consumer preservation in a SAFE-based product. While Kumar proved that his SAFE values are appropriate for regular consumer products, the Mashrabiya screen taken into consideration in this research may not meet his definition of a 'consumed product'. Nevertheless, the SAFE values proposed by Kumar (2008) will be examined according to the values put forward by Mashrabiya designers (architects and scholars) in the literature.

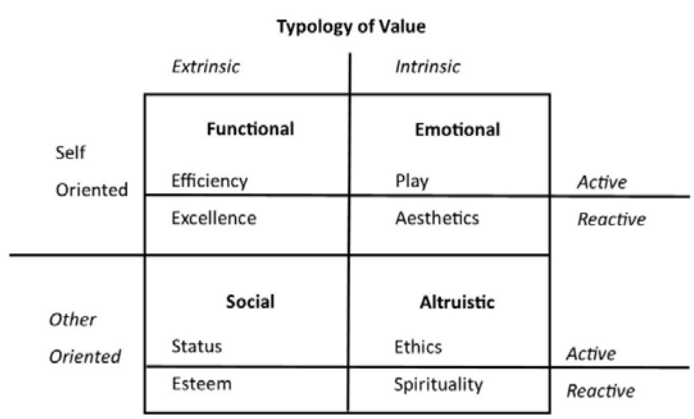


Figure 3-1: SAFE values (Kumar, 2008, p.25).

By comparing the general context of product design values with the specific context of an architectural product, a new set of values are needed. This research can contribute to the literature by customising a new set of values for the production of Mashrabiya screens as an architectural product. Kumar's (2008) values will be compared with the most common values found in the literature to date to re-envisage 'new SAFE values'. The values framework defined by Hui (2005) and Sidawi (2012) represents a comprehensive example of the literature-based values underpinning Mashrabiya design and reuse in the Islamic context see Figure 3-2 and Figure 3-3.

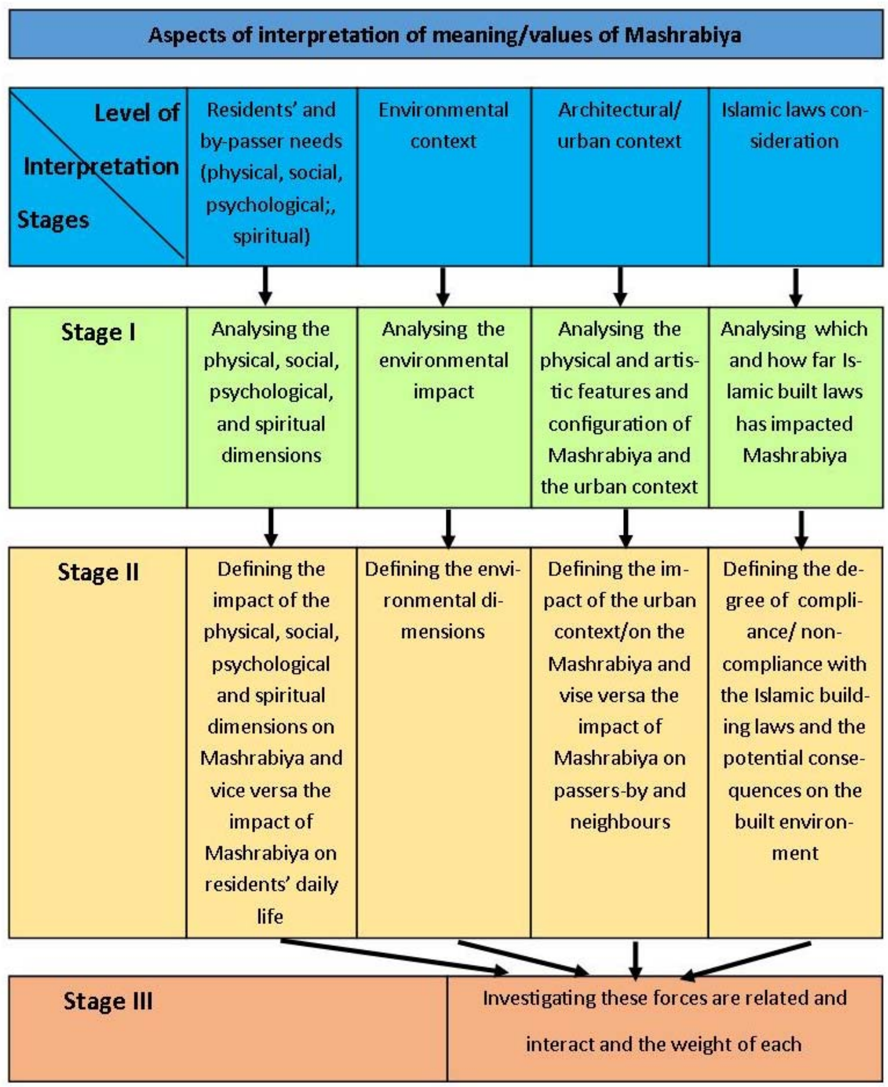


Figure 3-2: Mashrabiya values as researched by Sidawi (2012). Source: Sidawi (2012, p. 15) edited by Author.

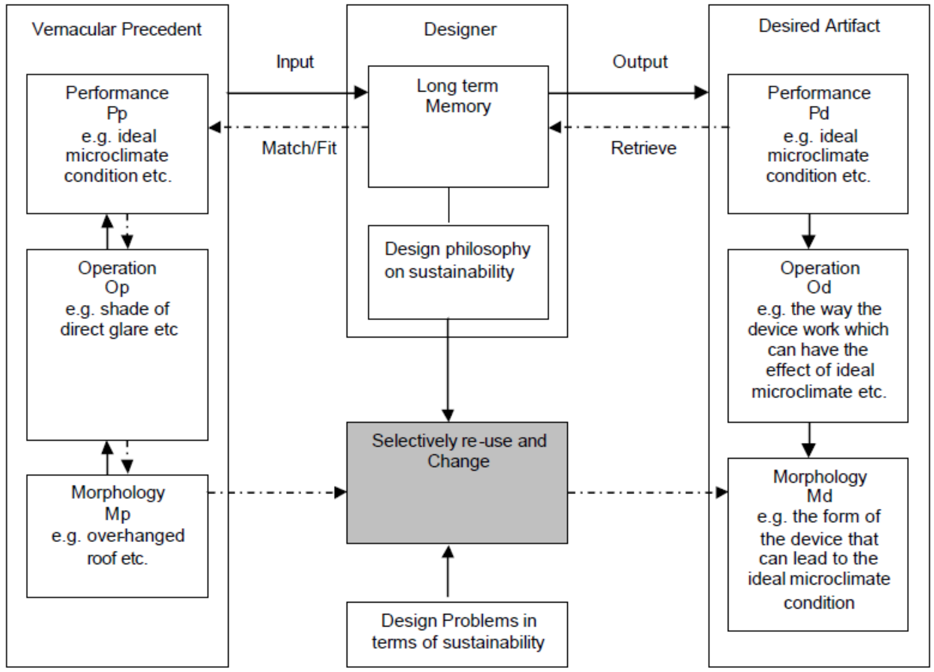


Figure 3-3: A research framework for the sustainability values used to upgrade the vernacular precedent to a new desired artefact, the case of the Mashrabiya screen as constructed by Hui. Source: Hui (2005, p.132).

Hui's (2005) framework mainly focuses on the values of sustainability and how these can be programmed into a model. The model allows its followers the ability to redesign a new Mashrabiya. His sustainable values are largely based on performance (functional or operational), and morphology values or aspects. His investigation concluded that through the adaptation of this framework, architects may utilise the values and form of sustainable precedent architectural elements like Mashrabiya to produce a new sustainable artefact.

While Hui's (2005) framework (see Figure 3-3) can be used to understand the transformation in value and form from Hassan Fathy's *Mashrabiya* to Frank Lloyd Wright's *Brise Soleil*, the material and social aspects are not clearly identified. A gap in the design stages of vernacular architecture in terms of sustainability still exists. In his review of literature related to sustainability in vernacular architecture, Hui (2005) demonstrates that there is a lack of valid information in the design thinking process. He states that existing vernacular architecture has been studied and critiqued by several authors, and so have the final vernacular design products in the literature; however, the essential conceptual thinking through which the final design is derived is not explored in his framework.

In Sidawi's (2012) framework (Figure 3-2) a more comprehensive set of Mashrabiya values emerge. Based on a literature search and an understanding of associated religious beliefs, Sidawi investigated specific architectural values. These values include environmental, psychological; social, spiritual, architectural and urban values, as well as Islamic laws. The complexity of his values was validated by a survey questionnaire. His conclusions, based on the responses of about 90 respondents, may not be based on a representative sample of the Saudi Arabian population. However, the overall ranked values he produced are very similar to those of Aljawder (2014), especially in relation to the importance of social values.

3.2 LITERATURE OUTCOMES

Mashrabiya screens have been associated with many design values that have practical implications; see Table 3-2. Most evident are the social and functional values of Mashrabiya. These contrasting values relate to the cultural and environmental context of the product of interest. Researchers interested in the form and functionality of Mashrabiya, such as Samuels (2011), Bendetti et al. (2010) and others, ignored the social impact of the new form generated. This is simply because the social value is linked strictly to Muslim countries and the visual privacy limits regulated by Muslim religious beliefs.

The strong importance of the social value of Mashrabiya has a significant effect on Muslim occupants. This factor has been researched by several scholars in the field (Fathy, 1986; Abdelgelil, 2006; Aljawder, 2014). As all of these researchers are working in an Islamic context, their dedication to considering the religious functions of Mashrabiya can be traced in their arguments and possible design outcomes. Therefore, any research or designs focusing on Mashrabiya production should not ignore the social context and cultural domains if designed for an Islamic context.

Furthermore, a more intensive search of the literature has found evidence of the aesthetic character and value of the Mashrabiya design. This is a valid characteristic and is repeated more frequently in the literature than the altruistic value. This may be due to the importance that architects and designers give to form. In many cases, the aesthetic value is more appreciated than the altruistic value. The reason behind this preference for aesthetic solutions may sometimes relate to conceptual design metaphors and architects' ideas. The preference for aesthetic values may also be the result of a parametric design or a general layout that may not necessarily function well in the case of a consumer product.

Nevertheless, hints at the low emotional value of a Mashrabiya screen are found exclusively in Almurahhem's (2008) and Sidawi's (2012) research. Their research was not supported by any new design proposals but was based on the influence of traditional Mashrabiya screens on their users' emotions. The restriction facing the validation of the emotional value is the reason behind the extinction of Mashrabiya in modern lifestyles. The emotional value has still only been traced in narrative research, which may not be applicable everywhere.

However, almost all researchers and scholars have integrated the functional value of Mashrabiya within their research. The literature review indicated that the influence of daylight and thermal quality as well as environmental factors and the characteristics of Mashrabiya as a product should be taken into consideration. Using a variety of scientific quantitative measurement tools, most researchers have validated the functional value of traditional Mashrabiya and most of the new product models based on it. Nevertheless, there is a clear overlap between the study of the function of Mashrabiya and its environmental role, as indicated by Almurahhem (2008). Almurahhem recommended consulting the wealth of literature regarding Mashrabiya performance and combining the investigation of functional and environmental factors to ensure that both visual privacy and environmental performance are covered in future studies of Mashrabiyas and Roshans.

The reliance on only one of these factors is seen in the research of Alshareef (1996), who considered Mashrabiya as merely a product of climatic conditions, excluding its function in responding to the privacy requirement in Islamic architecture. Furthermore, Aljofi (2005) asserted that his critical evaluation of the thermal performance of Mashrabiya and its potential as a source of natural ventilation should always be followed to produce environmentally responsive screens. In a study focusing on the environmental role of Mashrabiya, Abdelgelil (2006) also examined the environmental performance of Mashrabiya but distinguished air pollution as a main problem preventing the revival of the use of this screen in countries such as Egypt. The most recent study of a shape variable Mashrabiya screen by Karamata and Andersen (2014) proposed it as a flexible design that can minimise solar gains while maximising daylight and the view of the exterior. Their calculation and simulation was supported by a mock-up product that helps to combine both visual and environmental functions through real experimentation and program simulations. The previous studies indicate that although its functionality has been proven by many researchers in different engineering and design disciplines, it still has a challenging and vibrant value that should always be taken into consideration in new Mashrabiya production within new contexts.

Thus, by further reviewing the wealth of literature in the field of window shading designs, especially on Mashrabiya as an architectural product, a clear gap has been shown to exist. This gap relates to the economic value impact and the cost of current Mashrabiya manufacturing. This value can alter the impact of new Mashrabiya on its consumption rate. Furthermore, a real gap in the literature in addition to this economic value is evident in the lack of understanding of the complexity of designing Mashrabiya in 21st-century houses. Researchers like Abdelgelil (2006) have briefly touched on the subject of redesigning Mashrabiya within an affordable budget and through the use of new manufacturing methods.

Table 3-2: Scholars' opinions on the value of Mashrabiya in the conducted literature review highlighting research gap.

Source: Author contribution.

Researcher / Value	Social	Aesthetic	Altruistic	Functional	Emotional	Environmental	Economic
Aljawder (2014)	√	√	√	√			
Karamata and Andersen(2014)		√				√	
Alzoubi (2010)	√	√		√			
Benedetti et al. (2010)		√		√		√	
Almurahhem (2008)	√	√	√	√	√		
Samuels (2011)		√		√		√	
Sherif et al. (2012)	√	√	√	√		√	
Sidawi (2012)	√	√	√	√	√	√	
Hui (2005)		√	√	√			
Abdelgelil (2006)	√	√	√	√		√	√
Kotey et al. (2009)				√		√	
Radhi (2013)		√		√		√	√
Aljofi (2005)	√	√		√		√	
Wang and Bay (2004)		√		√		√	
Alshareef (1996)	√	√		√		√	
Hariri (1986)	√	√	√	√			
Fathy (1986)	√	√		√		√	√
Adopted value	√	√		√			√

Nevertheless, as new manufacturing technology revolutionises the market every day, awareness, experimentation and testing of new materials and production techniques is vital. This is particularly important because the original craft of Mashrabiya making relied on hand skills. Skilled craftsmen are rare nowadays, as explained earlier. This is why researchers should reconsider the economic factors and cost of using new manufacturing tools to reproduce Mashrabiya. The emergence of new digital craftsman techniques is also adding a new aesthetic value that may be distinctively researched as well.

The market value of Mashrabiya production remains to be documented as new knowledge. In the interior and architecture fields, the price and cost of such screens has never been documented and compared before. While each researcher may be familiar with the materials commonly used in his context or research area, a better general understanding of all possible Mashrabiya materials needs to be documented. Each type of material can have a different economic value and later can have implications for sustainability.

Therefore, Kumar's (2008) SAFE values can be adapted according to the design of a Mashrabiya product. The 'new SAFE values' for the production of an architectural product with a cultural constraint can be identified here. Note: the altruistic value has been replaced with the aesthetic value and the emotional value with the economic value as the result of the previous discussion.

- Social value: indicates the importance of the social and cultural setting, identifying how the design of Mashrabiya responds appropriately to the surrounding urban and cultural context.
- Aesthetic value: indicates how the Mashrabiya form and produced design fit into the fashion trends and visual preferences/values and context of the given culture.
- Functional value: indicates the use of the new Mashrabiya and its performative functions. It tries to answer whether the Mashrabiya achieves the environmental/climatic, social/cultural contextual criteria.
- Economic value: indicates how feasible and sustainable is the production, materiality and machine cost, assembly, transportation, installation and maintenance.

The new SAFE values can therefore be considered as a holistic approach to the creation of meaningful and practical Mashrabiya products. Figure 3-4 and Table 3-3 identify the reliability of SAFE as a framework against the Value Opportunity Analysis (VOA) used by Martin and Hanington (2010). Martin and Hanington (2010) define the VOA as a tool used to map the extent to which a product aligns itself between its aspirational qualities and people's idealised lifestyles. The VOA relies on emotional, aesthetic and identity factors that may not necessarily be identifiable in a product like Mashrabiya. The VOA can be used as an investigating framework for use on products of multiple brands. Hence, the technology and quality values can differ among various brands. However, the new SAFE values have a social value that has already been proven valid, together with identifiable aesthetics. Functional values are also identifiable and have been proven valid. The economic value in itself is not just identifiable through cost figures but is highly valuable for practice-based research and for use with products of a particular scale and type. Martin and Hanington (2010) support the concentration on the economic value as they noticed that customers are happy to pay a higher amount of money for the noticeable improvements an enhanced product can add to their lifestyle.

A Mashrabiya VOA report can be tested, as seen in Figure 3-4. Most of the 'low' value indicators represent an attribute that is not measurable or not applicable to Mashrabiya as a product. Since the 'low' values exceed the high to medium values, the VOA of a Mashrabiya might not be a reliable and valid source to use.

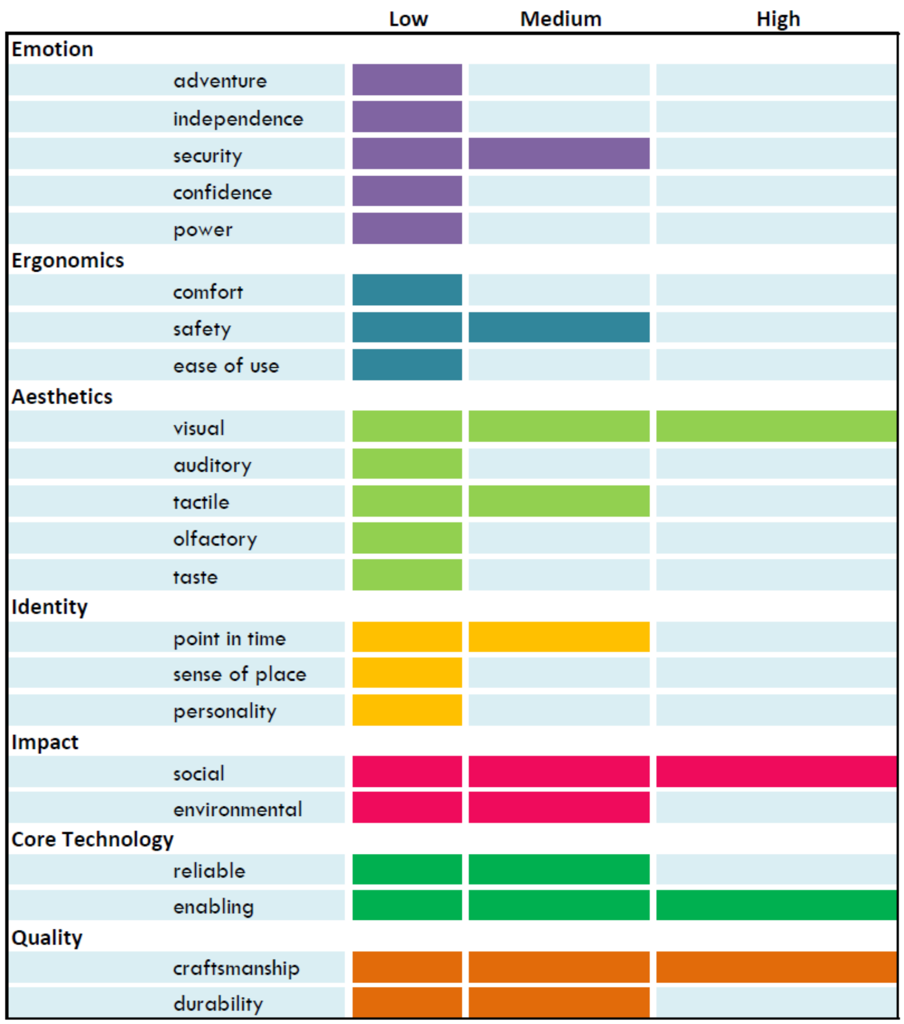


Figure 3-4 Mashrabiya VOA obtained from values in the literature. Source: Author contribution.

Table 3-3 Comparison and applicability of SAFE values vs. VOA values. Source: Author contribution.

SAFE FRAMEWORK		VALUE OPPORTUNITY ANALYSIS (VOA)	
Social	Highly valuable Has been proven	Rarely applicable	**Emotion:** adventure, independence, security, sensuality, confidence, power
Aesthetic	Identifiable	Identifiable	**Aesthetics:** visual, auditory, tactile, olfactory, taste
Functional	Identifiable Has been proven	Not definable	**Identity:** point in time, sense of place, personality
Economic	Highly valuable Has not been proven	Has been proven	**Impact:** social, environmental
		Not applicable, partially proven	**Ergonomics:** comfort, safety, ease of use
		Not acknowledgeable	**Core technology:** reliable, enabling
		Not applicable as craft is extinct	**Quality:** craftsmanship, durability

The new Mashrabiya SAFE values are outlined in Figure 3-5. All aspects related to the user have been categorised under the social value, while the form and cost as well as the function controls the other values. It is important to note that while this framework is valid for Mashrabiya, it can also be valid for other culture-social based products of an architectural and urban context, which can be developed in further research.

Figure 3-5 SAFE value framework for new Mashrabiya design. Source: Author.

3.3 3D-PRINTED MASHRABIYA (3DPM) RATIONALE

The definition of a 3D-printed Mashrabiya (3DPM) relies on the use of a large-scale 3D printer to produce a lattice screen that can be used as an exterior window shading device. The design of the screen can be printed from a CAD parametric file designed by architects or interior designers. This device is argued to be most needed in Islamic countries (Almurrahem 2012, Abdulsalam and Rihan 2013, Headley et al. 2015). This research will focus on producing such a screen for houses in Bahrain as an example of an Islamic country. A new set of values should be taken into consideration as a result of the investigated wealth of literature. Validating this new approach to reviving the use of Mashrabiya in the Bahraini context relies on the following rationale:

1- Lack of awareness of the social role Mashrabiya played and can play again in modern Bahraini houses.
2- Decline in the use of skilled craftsmen in producing lath-type Mashrabiya.
3- Reliance on manual crafts to produce heavy gypsum screens that do not suit modern homes.
4- Preference for a modern architectural facade over traditional architecture that includes Mashrabiya.
5- Dependence on CNC machines and 2D-designed patterns as a way to modernise Mashrabiya.
6- Lack of a holistic approach to redesign architectural elements of culture and social obligation like Mashrabiya.
7- Inadequacy of several Mashrabiya materials and manufacturing techniques to suit new environmental and aesthetic demands.

8- No industrial market documentation of Mashrabiya production cost estimation and material range.
9- Drawback of the utilisation of new manufacturing technology to reproduce successful vernacular precedent forms like Mashrabiya.
10- A need for a new set of values that are reliable in terms of Mashrabiya users' preferences.

3.4 SAFE VALUES FRAMEWORK FOR VALIDATING 3DP MASHRABIYA

In view of the problems facing the current Mashrabiya revival, a primary motivation of this research is to bridge the gap between the knowledge base of research results and design practices. It is very important to look into the architectural values of Mashrabiya from a practice-based point of view. This can be achieved through studying their context and attributes and problem-solving processes as well as the economic forecasting of design possibilities in 3D printing.

In product design, understanding the values that define the product's importance is an essential part of the design process. With reference to secondary data and through addressing gaps in the literature, the values of Mashrabiya can be grouped mostly under social, aesthetic, functional and economic ones.

In developing the new framework for evaluating the value of a new Mashrabiya design resulting from the research, the author explored both architectural and product evaluation criteria. SAFE (social, aesthetic, functional and economic) values were distilled and developed based on research presented in the literature review (Veryzer 1995; Kumar 2008; Sidawi 2012). SAFE values question and validate targeted value parameters to define the success of a product in an architectural context. The four criteria in the framework evaluate the following parameters:

- **Social** – Within the social and cultural setting, how does the design respond appropriately to the urban context and religious Islamic beliefs?
- **Aesthetic** – How does the produced design fit into the fashion values and context of the given culture?
- **Functional** – What performative functions does the product achieve in the context of social/cultural, environmental/climatic, and emotional criteria?
- **Economic** – How feasible and sustainable is the production, transportation, assembly, and installation?

However, since some of the values cannot be achieved or calculated due to the fact that a real object cannot be manufactured, some of the values were reduced. See Figure 3-6.

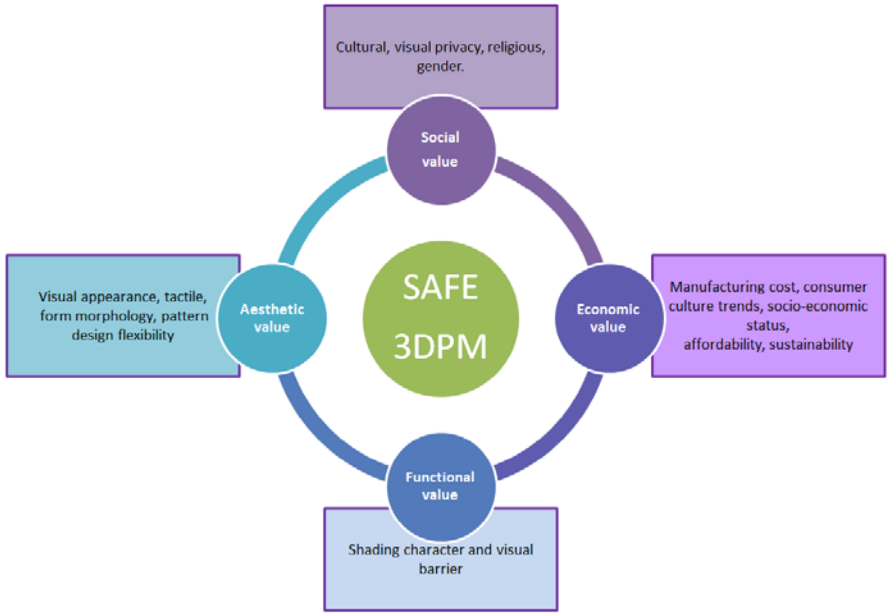


Figure 3-6: 3D-printed Mashrabiya (3DPM) SAFE values. Source: Author contribution.

3.5 REFINEMENT OF RESEARCH QUESTIONS

Having highlighted the importance of taking a holistic approach involving SAFE values and aspects in the design of a new Mashrabiya, the research questions can be refined. The aims and objectives outlined in Chapter 1 will be revisited so that they reflect the SAFE values. The reason behind choosing to take a holistic approach to new Mashrabiya design is the critical importance of the social and cultural context that shapes the other values. The sole focus of this research is not on function; rather, the research hypothesis argues that it is important for the four SAFE values to be considered collectively.

The conclusion of the literature review, as seen in Table 3-2, highlights the research gap and the contribution of this research. However, the theoretical and practical process to be undertaken in this research is derived from the importance of the holistic approach itself. Rather than choosing to conduct an in-depth investigation on economic viability, which constitutes a gap in the literature, it was decided instead to investigate the four values collectively without risking a shallow analysis of each. Therefore, the modified research questions should address why the research focuses on four and not one aspect.

The research title could have been about this holistic approach to the redesign of Mashrabiya. However, this has been overlooked in order to follow the rule of not using acronyms in the research title. The research, however, questions the impact of ignoring one of the SAFE values in a Mashrabiya design process. It also acknowledges that all values interweave and interact with the other values and that any single value cannot be ignored. Specialists might question and argue against the use of the word ‘holistic’. In response, it may be stated that the Mashrabiya has a complex nature, where cost, performance, culture, lifestyle, and other factors extend beyond a sensory experience but touch a nostalgic and a much deeper emotional level.

The argument used here addresses the fact that looking at one factor or value would not give a complete picture of the research problem. The importance of SAFE is also connected directly to 3D printing but can be generalised and adopted by new manufacturing technologies that emerge in the future. This PhD research therefore contributes to the body of knowledge in defining a process that combines the most important values to be considered in the example of the design of Mashrabiya. Nevertheless, the hypothesis behind SAFE can also be used to generate any new product of a cultural aspect.

By understanding and implementing the SAFE values for 3DP Mashrabiya this research frame the significance of Mashrabiya screens and its historical background. It articulates the reasons behind its decay and the possible opportunities to revive it as a product with visual and emotional characteristics. The validity of the economic value by itself forms a convenient and reliable argument for application in real-life possibilities and forecasts. The refined questions are reworked in Table 3-4.

Table 3-4: Refined research questions to apply SAFE values to 3DPM. Source: Author.

<table>
<tr><th>Original research question</th><th>SAFE 3DPM</th><th>Refined research question</th></tr>
<tr><td>What is the need behind reviving the production of traditional Mashrabiya screens?</td><td>Social, Aesthetic, Functional</td><td>Why is the use of Mashrabiya declining in Bahraini architecture?
Is there a need to revive the use of it?</td></tr>
<tr><td>What are the current manufacturing processes used to produce Mashrabiya?</td><td>Functional, Economic</td><td rowspan="4">What are the current manufacturing processes used to produce Mashrabiya and what are the associated economic implications of such processes?

What are the potential benefits and obstacles in adopting 3DP techniques to produce Mashrabiya?</td></tr>
<tr><td>How much does it cost to produce Mashrabiya locally?</td><td>Economic</td></tr>
<tr><td>How much will it cost to 3D print Mashrabiya screens?</td><td>Economic</td></tr>
<tr><td>What are the benefits and obstacles of each manufacturing technique?</td><td>Aesthetic, Functional, Economic</td></tr>
<tr><td>When will it be economically viable to produce 3DP Mashrabiya in Bahrain?</td><td>Social, Aesthetic, Functional, Economic</td><td>What are the values that would be used to determine the validity of 3DP in producing Mashrabiya?</td></tr>
</table>

3.6 SELECTION OF AN APPROPRIATE METHODOLOGY

When design intersects with research, one influences the other. Using research knowledge and design skills to deploy the appropriate method to solve the research aim and objectives and fulfil the design aspiration can be highly challenging.

The SAFE holistic approach looks at the four values collectively without ignoring any of them. These values are not static and they change in a way that influences the final product. It may be claimed that losing an aspect of each value can result in a different product being produced each time. The challenging factor here is to integrate the four value parameters at once. A rating and conclusion for each value will be obtained from the collected data. The study therefore can rely on the primary original data gathered by the researcher or can rely on secondary data from the literature. Data from the literature will feed into the main contribution to new knowledge. Therefore, the main contribution will highlight the benefits of the holistic approach in comparison to other approaches in the design and manufacturing field.

This research will rely partially on secondary data due to the limitation of time and to avoid repetition of already validated values, such as the cost and 3DP technology forecasts generated by Wohlers Reports from 2008 to 2014. Validated Mashrabiya values, especially in terms of functional and social values, were discussed earlier. A point to remember is the fact that no earlier researcher has put these values into research and design parameters; this means that the present research takes an original approach that is supported by a proof-of-concept model.

The shortcomings of other authors in the field constitutes an advantage for SAFE 3DPM research. The present research will also take into consideration the results of key authors in the field. When analysing their results, comparison with other authors' work and outcomes will be highly valuable to strengthen the results of this research. The outcome will not just target future researchers but shall aim at helping architects and designers in making better design decisions when redesigning Mashrabiya.

The following chart in Figure 3-7 indicates the most related theoretical and practical methods used to validate SAFE 3D-printed Mashrabiya. Key authors' results have been selected according to the following reasons:

- Context of their research, which matches or is similar to the Bahrain context.
- Their research into Mashrabiya design was conducted in the last 10 years as technology and architecture can change dramatically within a decade.
- Theoretical claims are supported by physical evidence or scientific figures.
- Their research includes manufacturing and product cost figures from the past 5 years only as 3D printing and architecture were not very developed earlier.

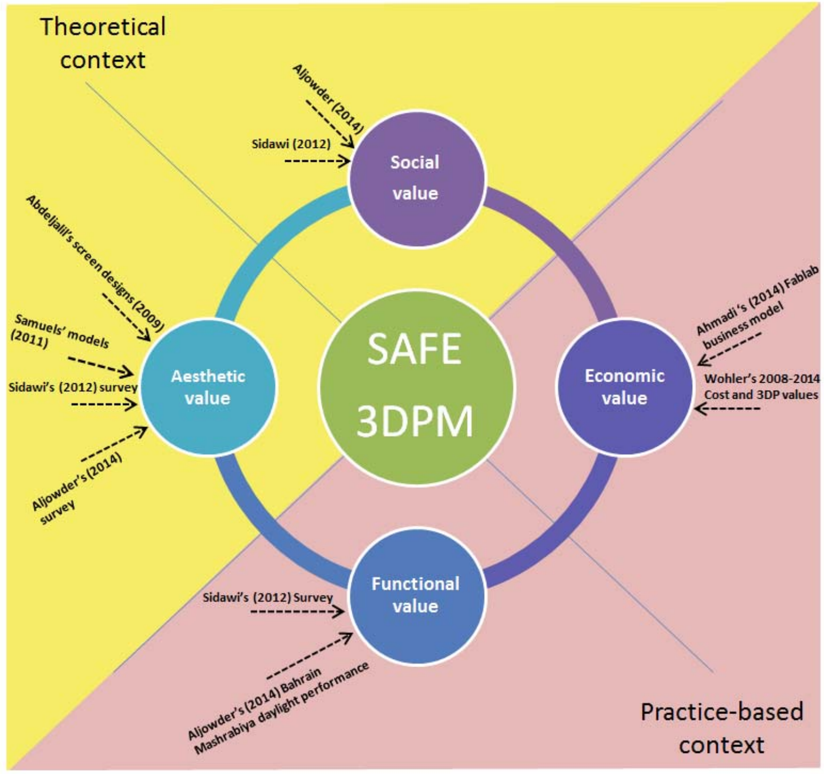


Figure 3-7: Contextualising the framework within appropriate theoretical and practice-based methods. Source: Author.

While the methods will be discussed in more detail in the next chapter, it is important here to note that the methods range between theoretical and practice-based ones. This is due to Mashrabiya being a new product of 3DP technology that would require a theoretical base to start its new sustainable design. Although evidence has been collected from architecture and research about the new possibilities of designing Mashrabiya, no economic study has to date been conducted. This may be related to the fact that the new projects containing new Mashrabiya are mostly made for a particular project and do not target the general public or the local market. Hence, the production of a new Mashrabiya should take possible technology costs into consideration, as documented in reliable sources like the Wohlers Reports.

3.7 CHAPTER CONCLUSION

This chapter has provided an explanation of the framework used to triangulate Mashrabiya between theory and practice. It has considered Mashrabiya values throughout time and scholars' work alongside the values found in product design.

A holistic approach to be implemented through the adaptation of a new SAFE framework has been analysed based on Kumar's (2008) SAFE values. The altruistic value in Kumar's (2008) value framework has been substituted with aesthetic in the new SAFE values for Mashrabiya. This is a result of the fact that aesthetic qualities were found to best represent the Mashrabiya in the literature review. Moreover, the emotional value has also been changed to the economic aspect. This was also a result of the literature review, as it has been concluded that economic factors can highly determine the way in which a Mashrabiya can be adopted or ignored in new modern house designs.

The present research, focusing on reproducing a Mashrabiya screen using the new 3D-printing technology, is highly reliant on both aesthetics and economics without ignoring the already validated social and functional phenomena of Mashrabiya. This is due to the nature of the technology itself, which can produce highly complex geometry. Highly complex geometry directly connects to the aesthetic appearance as a key value. Also, the machines and prices of large-scale 3D printers is a new value to take into consideration in this type of 3D manufacturing. The application of the SAFE values is therefore used in this research as way to approach and analyse the data.

The following research framework (see Figure 3-8) represents a general overview of how the research problem is approached. It responds to the modified questions raised in this chapter and it gives a sequential overview of the methods to be adopted to answer the new research questions. The new research questions are:

1. Why is the use of Mashrabiya declining in Bahraini architecture?
2. Is there a need to revive the use of Mashrabiya in Bahraini architecture?
3. What are the current manufacturing processes that are used to produce Mashrabiya and what are the associated economic implications of such processes?
4. What are the potential benefits and obstacles in adopting 3D printing techniques to produce Mashrabiya?
5. What are the values that would be used to determine the validity of 3D printing in producing Mashrabiya?

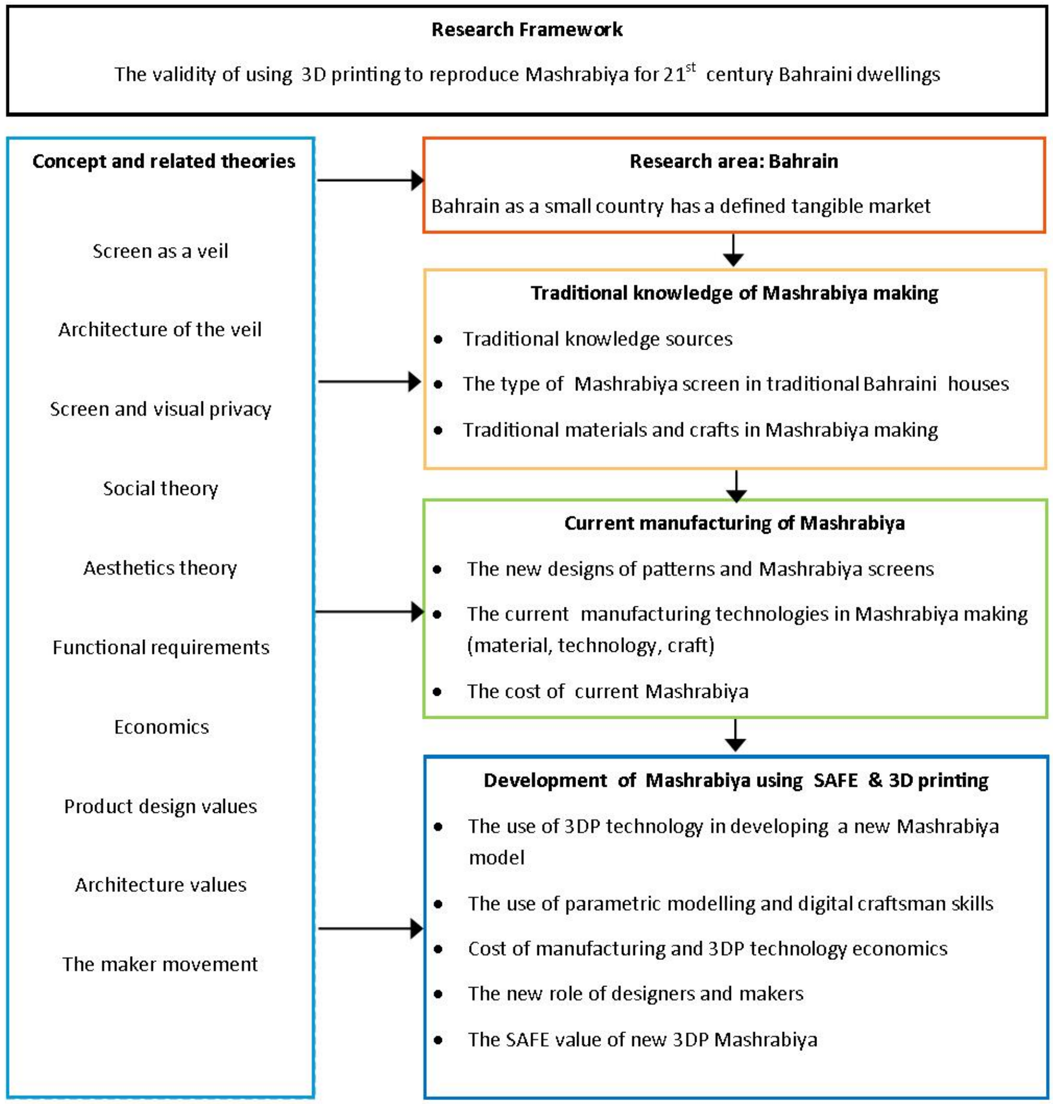


Figure 3-8: SAFE 3DPM research framework. Source: Author.

CHAPTER 4

*"You can never empirically or logically determine the best approach. This can only be done reflectively by considering a situation to be studied and your own opinion of life. This also means that even if you believe that one approach is more interesting or rewarding than another,
we … do not want to run one approach above the other. In fact, we cannot on any general ground. The only thing we can do is to try to make explicit the special characteristics on which the various approaches are based."*

Arbnor and Bjerke (1997) cited in Blaxter, Hughes and Tight (2006), p.58.

CHAPTER 4: METHODOLOGY

4.1 INTRODUCTION TO METHODOLOGY

The Mashrabiya screen featured in this research span several major disciplines: Material Culture, Architecture, Interior and Product Design, and Manufacturing Economics. As a wide range of background material was obtained through the literature review, there is a need to take a holistic approach towards solving the research problems indicated earlier. A combination of methods collected from different disciplines is used and is based on the literature findings to address this research aim and objectives. The various collective methods adopted fill the gabs in the induvial method data that may targeted certain research objectives. This chapter explains the general reason for selecting each method and how this method is utilised to fit the aims and objectives of this research. The aim of this chapter is to select methods that would bridge the gap between academic research studies, historical documentation, and current and possible manufacturing techniques within global and local markets. This was reflected earlier in the research framework chapter and SAFE (Social, Aesthetic, Functional and Economic) value application, refer to Figure 3-7.

As defined in Chapter 1 any research is guided by a set of beliefs that are widely known as paradigms, as argued by Kuhn (1970) cited in Bryman (2012) and supported by Killam (2013). Collins (2010) uses the metaphor of a ‘lens through which we view the world’ to define research paradigms. The nature of the world and the research problem and assumptions would therefore require different ‘lenses’.

Although this research subject has an established wealth of beliefs in cultural and functional research and architectural practices that are built on a set of ontological and epistemological proofs and practices observed in the literature, the paradigm that best delineates this research is the methodological one. Wainwright (1997) defines the methodological paradigm as referring to how the researcher carries out research in the pursuit of knowledge. This is an appropriate paradigm since this research relies on the previously explained SAFE framework to understand knowledge obtained in this area. The methodological paradigm adopted in this research assures the compliance of data with the research aim and objectives via a mixed method approach. This paradigm is recommended to be most suitable by Creswell (1994) to address the research topic and its multi-disciplinary nature the span between architecture practice and manual craft as well as product design economics.

The research argument ethos and method-selection fall under the qualitative methodological paradigm using an inductive research approach. Bernard (2011) defines inductive research as consisting of the search for patterns from observation and the development of explanations for those patterns through a series of hypotheses. Reflectively, the SAFE framework is considered here as the set of obtained themes which can generate a set of hypotheses at the end of the research period. Collins (2010) states that understanding the context within which research takes place and not focusing on cause-and-effect relationships is the strength of an inductive approach. Unlike the deductive approach, which relies on scientific principles and the move from theory to data in a structured quantitative manner, the inductive approach yields an understanding of the meanings and values attached to various contexts, such as the social, aesthetic, functional, and economic aspects. Collins (2010) also indicates the flexibility of the inductive approach, in that it allows changes of emphasis as the research develops, involving the researcher in the process and having a lower need to generalise the results gained from qualitative data.

Unlike the quantitative paradigm, this research in the qualitative paradigm is contextually bound to the architecture of Bahrain and the Middle East and therefore the research outcomes may not be generalised to the global world. The methodologies and patterns developed are used merely for understanding the market and for providing accurate and reliable facts through verification, as recommended by Creswell (1994). The research structure uses a theoretical framework suggested by Maxwell (2005) and Bryman (2012) that can serve two purposes. Firstly, it will demonstrate how this research further contributes to what is already known from other subject-related research within disciplines such as architecture, product design, and additive manufacturing economics. Secondly, it will show the research gaps and how the present study can contribute to the body of knowledge.

The methods used herein are derived from understanding the research problem and the qualitative paradigm model in which it fits. The study adopts a mixed methods or a 'multi-method' approach, as described by Collins (2010), whereby a quantitative survey of Bahraini residents and manufacturing costs was combined with qualitative methods to explore the research area. Combining the data and influencing the stages of research are key concepts in the methodology adopted here.

The methods were divided into three interlinked data collection phases ranging between theoretical and practical-based methods (see Table 4-1). The first phase analyses four case studies about buildings that have revived the use of Mashrabiya screens in local, regional, and global contexts. The trends and themes derived from the literature and secondary data influenced the formulation of the public survey questions. Survey data gathered then helped in forming the next phase. The second phase investigated professional architects' and designers' work and their feedback, as well as local and global manufacturers' opinions and expertise in producing Mashrabiya screens. Local market Mashrabiya cost calculations and international 3D-printed screen estimation will also be included in the analysis.

A developed 3D-printed Mashrabiya (3DPM) prototype was developed in phase two and three then discussed in focus groups in the last phase to obtain feedback on its functionality and aesthetic value. Thus, feedback and discussion about local mindsets, purchasing power and preferred design trends can help forecast the viability of such a product in Bahrain and the Middle East market in the coming years within professionals and end users group focus groups. The use of a hybrid mixture of qualitative and quantitative methods and the combination of theory and practice in this research can benefit the resulting findings, as reasoned by Bryman (2012, p. 633) (with modification):

1- *Triangulation* of findings can be mutually cooperative by using both qualitative and quantitative methods.
2- *Credibility*, claiming that employing both approaches enhances the integrity of the findings.
3- *Completeness*, since the researcher can better comprehend the area of enquiry using both methods.
4- *Offsets*, which allow the researcher to offset the weakness of one of the methods of the qualitative or the quantitative data against the strengths of the other.
5- *Process*, combining the structure that quantitative procedures take together with the sense of process that distinguishes the qualitative data.
6- *Explanation* research benefits from using one of the two research methods to explain findings generated by the other.
7- *Context*, especially related to this research as contextual understanding explains the survey results.
8- *Confirm and discover*, when costly qualitative data is used to generate hypotheses, then quantitative data are used to test them within a product model test.

4.2 CHOICE OF METHODS

This section describes the research methods that were adopted and justifies their selection over other possible methods. This is followed by outlining some methods that were rejected due to them being unsuitable for this research within the given timeframe and budget. A mixed methods approach was used to generate primary data with support from secondary data. Table 4-1describes the type of methods used.

As recommended by Collins (2010) and Curedale (2013), the choice of methods was also influenced by the research taking place in a known Bahraini context, the Mashrabiya screen users being known to be Bahraini locals or residents with a SAFE insight to the subject. As claimed by Collins (2010), the 'multiple' or mixed methods approach uses research tools from both qualitative and quantitative methodologies to answer research questions. The following table represents how each method was utilised to answer solely or collectively the research's main questions.

It is also important to highlight here that each method of data collection may be more suitable for one part of a question than another. 'Responses' to questions are seen from different perspectives, and data is then layered to conclude where the weaknesses of some methods for a question are cancelled by the strengths of other methods, as advised by Bryman (2012) and Collins (2010). Therefore, a triangulation of different methods and data helps to analyse the SAFE values more efficiently.

Table 4-1: Mixed-methods approach to answering the research questions. Source: Author.

RESEARCH QUESTIONS	DATA COLLECTION APPROACH	SAFE value aggregated
1. Why is the use of Mashrabiya declining in Bahraini architecture?	-(Phase 1) Case study analysis of existing projects -(Phase 1) Initial interview with academics/residents -(Phase 1) Mashrabiya survey as secondary data from literature + SAFE framework -(Phase 1) Survey (B) of the general public	Social, Aesthetic, Functional, and Economic
2. Is there a need to revive the use of Mashrabiya in Bahraini architecture?	-(Phase 2) Interviews with academics, architects, local manufacturers -(Phase 2) Workshop site visits	Functional and Economic
3. What are the current manufacturing processes that are used to produce Mashrabiya and what are the associated economic implications of such processes?	-(Phase 2) Interviews with local manufacturers -(Phase 2) Secondary data from literature if found	Functional and Economic
4. What are the potential benefits and obstacles in adopting 3DP techniques to produce Mashrabiya?	-(Phase 2) Interviews with global manufacturers -(Phase 2) Secondary data from industry reports -(Phase 2) Production of proof-of-concept model	Functional and Economic
5. What are the values that would be used to determine the validity of 3DP in producing Mashrabiya?	-(Phase 3) Interviews with academics/architects/designers and global 3D manufacturers -(Phase 3) 3DP exhibition visits -(Phase 3) Secondary data from industry reports -(Phase 3) Focus groups of professionals -(Phase 3) Focus groups of potential end users	Social, Aesthetic, Functional, and Economic

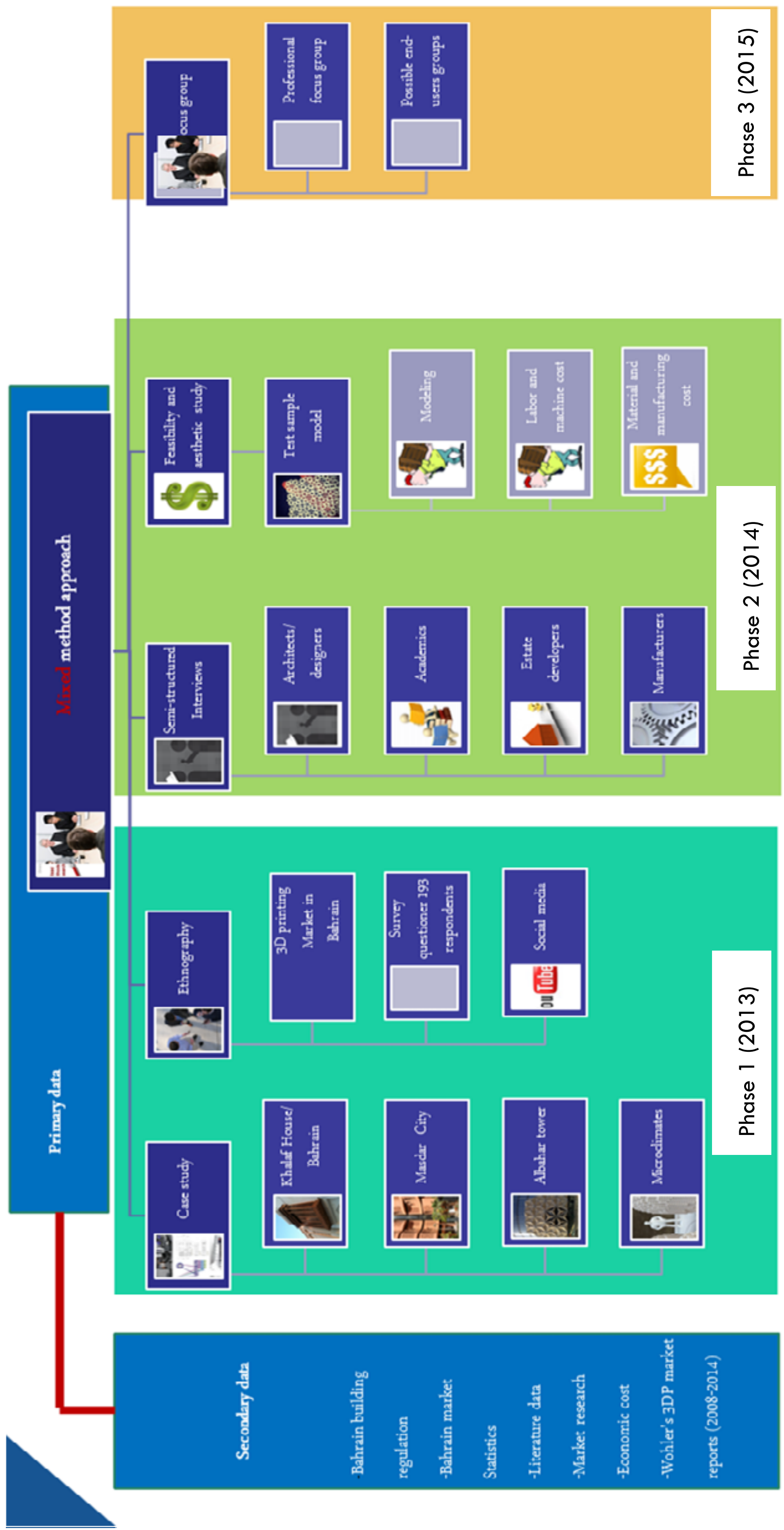


Figure 4-1: Research methods used. Source: Author.

4.2.1 Selected research methods

The several key researchers and scholars mentioned in the earlier literature review adopted a variety of methods that responded to the complexity of the subject in focus. From social to aesthetic, and from functional to economic understanding, Table 4-2 shows the relationship between the key authors and the selected methods that they have adopted to reach their conclusions.

Case study research is a very common method that has been adopted by several architecture scholars, such as Hariri (1986), Abdulgelil (2006), Sidawi (2012), Aljawder (2014) and others in researching the Mashrabiya. The benefits of examining existing projects in terms of its visual and contextual language and how it performs helps in critically analysing key research problems or phenomena. This is evident in the critical visual analysis conducted by Abdelsalam and Rihan (2013) in order to understand how the concept of Mashrabiya has been regenerated through different contemporary projects. By relying on both printed and online sources or visiting existing projects, the case study method can be considered an essential stage in understanding the contextual influence on a product. For example, the product could be a building or a window screen, as seen in Wang and Bay's (2004) study of semi-open spaces and high-rise dwellings, before they parametrically studied window behaviours. The benefit of this method is evident for researching historical buildings and vernacular architecture, where forms and voids respond to the culture and environmental constraints. It enables an understanding to be gained of the link between memory and the nostalgia of living within Roshan/Mashrabiya, such as the study conducted by Almurrahem (2008). Consequently, the merits of adopting a case study research method can highly benefit this study and help triangulate its SAFE value indicators.

The second most common methods used are survey questionnaires and interviews. Survey questionnaires are a relatively easy method to gain representative data from a large population. Both Sidawi (2012) and Aljawder (2014) relied on survey results to draw major conclusions about their targeted population with reference to Mashrabiya use. The data presented and used by these scholars is supported by other qualitative or experimental methods to increase the validity of the results. The method of surveying possible window end users and understanding their social demands and functional aspiration is therefore adopted by the author.

Other methods found in the literature be implemented by the author include interviews, graphical simulations, and actual prototypes as proof of concept. Full-scale virtual and actual prototypes of the Mashrabiya screen are evident in the literature. However, only one set of scholars, Benedetti et al. (2010), managed to produce a full-scale wooden screen resembling the Mashrabiya in order to test the best solid wood material to use. Issues of cost and fabrication play a major role in researchers' adoption of this method. Hence, Abdulgelil (2009) relied on CAD drawings to represent her new Mashrabiya concept inspired by the Japanese Mechia Goshi screen, while

Samuels (2011) relied on CAD/CAM tools to provide smaller-scale screens that were designed according to the environment and from his calculations. This is a common issue with manufacturing large-scale products without research funds or industry partners. The importance of having a visual model as a proof of concept and as an example of a manufacturing possibility can highly benefit the claim of this research. Therefore, it was recommended by the supervision team to have a partial proof-of-concept model to prove the validity of the new 3DP technology in the field of architectural precision.

Printing a large-scale 3D Mashrabiya is difficult and costly. It was not possible to secure funding to print the entire experimental model being developed in this research, due to the high costs involved. Therefore, the aim was to produce partial screen models instead. Moreover, realistic renderings and visuals of the screen needed advanced parametric modelling skills, these skills are more accessible. This led to understanding the importance of visualising the entire context of a 3DP Mashrabiya on a building facade or in an interior setting. Therefore, it is important to gain insights from interviews with end users or through conducting focus groups, or simply provide contextual information about the designed product, as recommended by Samuels (2011).

The importance of the aesthetic appearance of the designed 3D Mashrabiya is parallel to that of its manufacturing cost. The literature has shown a lack of knowledge about Mashrabiya manufacturing costs and market research. Although Aljawder (2014) hinted about wood and GRC screen costs in Bahrain, and Ahmadi (2014) estimated the feasibility of a Fab lab with CNC and 3DP in Bahrain, neither truly covered the market of both technologies. It is therefore essential to conduct such a feasibility test and market research on Bahrain window screens in order to find raw data about the product of interest in order to verify its economic validity.

The Mashrabiya screen is considered a rich research subject for social scientists, architects, designers, material culturist and historians. Using a framework to triangulate all the information or subjects of interest is therefore highly recommended. Frameworks developed by Hui (2005), for example, have helped to shape the data and pinpoint important design conclusions within a sustainability context. While Sidawi's (2012) Mashrabiya value framework made data more precise in in its architecture and religious context while conducting his survey questionnaire and data analysis. With reference to scholars and others, the SAFE values are used as a framework to triangulate the information examined and envisaged in this research.

In conclusion, a variety of methods have been explored in literature; choosing the most frequently used method is an easy research task. However, taking into consideration the research problem, questions, and aims has dramatically controlled the selection of the method used. With regard to some aspects of the research problem, like cost and economics, only very basic information was found in the conducted literature review. This has created a gap in the knowledge that this research contributes to. Moreover, the complexity of the Mashrabiya as a product makes it easier to be studied in terms of its standard functions, such as social and environmental aspects, but very challenging to validate economically and aesthetically using 3DP.

These factors resulted in the researcher utilising a variety of both qualitative and quantitative data to form conclusions and make forecasts in a holistic approach. This holistic approach, if proven viable, can become a method of its own in researching complex social redundant products of the new digital age.

Table 4-2: A comparison of key scholars' adopted research methods. Source: Author contribution.

Scholar / Methods	Case study	Survey questionnaire	Interviews	Actual prototype	Virtual prototype	Computer simulation	Site experimentation	Graphical simulation	Theoretical framework	Materials data	Feasibility study
Aljawder (2014)	√	√				√					
Ahmadi (2014)		√	√								√
Karamata and Andersen (2014)					√	√		√			
Vakilinezhad et al. (2013)	c					√					
Sheirf (2012)						√		√			
Abdulsalam and Rihan(2013)	√										
Alzoubi (2010)						√		√		√	
Benedetti et al. (2010)				√		√	√			√	
Almurahhem (2008)	√		√					√	√		
Samuels (2011)	√			√		√		√			
Sherif et al. (2012)					√	√		√			
Sidawi (2012)	√	√							√		
Hui (2005)	√								√		
Abdulgelil (2006)	√		√		√	√		√			
Kotey et al. (2009)	√					√				√	
Radhi (2013)	√					√	√			√	
Aljofi (2005)	√			√	√		√				
Wang and Bay (2004)	√					√		√	√		
Alshareef (1996)	√				√	√				√	
Hariri (1986)	√	√									
Fathy (1986)	√				√			√			
Adopted methods	√	√	√	√	√			√	√	√	√

4.2.2 Rejected research methods

This research has rejected a few methods conducted by scholarly researchers in the fields of architecture and Mashrabiya design. As listed in Table 4-2 and explained here, due to time and subject limitations or contradictions with the research aims and objectives, some methods were rejected or considered for use in possible future work.

Narrative studies used by Akbar (2005) and Almurrahem (2011) required an in-depth analysis and data from people who lived or are still living behind the Mashrabiya. Unfortunately, this was a very difficult task to accomplish, as few Mashrabiya samples still exist and the elderly who used to live within such houses with the Mashrabiya are very difficult to find and most women can be conservative in speaking about it.

Similar to Benedatti et al. (2010), a real scale of a 1 x 1 metre Mashrabiya model was not used in this research. This is due to the high feasibility costs of the designed product, the limitation of its funding, and the 3DP technology infancy in this area and scale. Instead, a partial proof of concept was modelled and printed to give a better representation of the idea. Application for grant funding to support a full-scale 3D print of the proof of concept was submitted to Kansas State University RECG. If funding is approved, printing and production analysis will fall outside the time scale of the research timeline of this PhD. This is considered as an area of future research after the product has been validated by SAFE, which is the main aim of this PhD. As an alternative, the researcher will rely on the partial SLS 3D print product funded by DMU and use this along with realistic visuals and animation of the new Mashrabiya model to better explain the concept and research argument.

The business model is one of the methods that has been used to support the validity of new economic market predictions and forecasts. However, this also conflicts with the holistic approach of this research. It might also be looked at as a way of promoting the capabilities of the new Mashrabiya as an 'innovative' product. To remain in focus and reflect the true aims and objectives of the research, this model was replaced by an economic one that could hint at the economic viability of the new Mashrabiya and yet neither advertise nor market it as a pure product invention. This was accomplished by keeping in mind the fact that the research of this thesis is based on more complicated cultural, aesthetic, and functional qualities that might be overlooked if business benefit was the driving force behind the research.

The wealth of literature about the Mashrabiya as a product of an architectural scale and yet at the same time an environmental facade device made it a rich scientific subject for daylight specialists like Aljawder (2014), Samuels (2011), Aljofi (2005), and Alshareef (1996). Aljawder relied on a virtual model built in EcoTect and supported by Radiance to compare the quality of light between a window with Mashrabiya and another without it. Collectively, Aljawder (2014), Samuels (2011), and Sherif (2012) merit the Mashrabiya as a better shading device that can respond to social and environmental contexts. Due to the depth found in the daylight quality research on Mashrabiya, a simulation model will not be used as a method here. Future research based on SAFE 3DP Mashrabiya can look into this aspect. What really matters for present purposes is to prove its aesthetic quality, which is something that none of the scholars investigating daylight have investigated in detail in terms of design. Furthermore, the complexity of the 3DP model and the density of its parametric form, as well as the uncertainty regarding its building construction materials, has delayed the adoption of such a simulation technique.

The thermal simulation of Shanashel, the Persian Mashrabiya, has already been proven effective by Veklinezhad et al. (2013) in Iran. In Egypt, Sherif (2012) has also conducted a series of experiments via a simulation software program called EnergyPlus to best analyse the relation between Mashrabiya perforation and its thermal qualities.

Coupling lighting and energy simulation are well-known methods used to calculate the building's energy requirements in relation to the global illumination environment. Alzoubi (2010), using the Lightscape software, claimed that this combination of simulation methods is important. His measurement of shading devices and the distance of louvres in relation to the quality of light penetrating an existing office room helped to decrease energy consumption while being able to maintain a good lighting quality in an interior space. Conducting his method under the postpositivism system of inquiry is therefore effective and reliable if a fixed form, depths, and perforation ratio are available.

This method has been rejected here since the thermal and daylight quality of the Mashrabiya has already been proved to be effective and there is therefore already a wealth of knowledge and literature on the environmental and functional role of the Mashrabiya. By following the methods of Alzoubi (2010), Sherif (2010), Veklinzhad (2013) and Aljawder (2014), the author can conduct future research in support of 3DP Mashrabiya, once it has been validated in this research.

4.2.3 Validity and reliability in mixed-methods research

Validity is an essential key to effective research. Blaxter, Hughes, and Tight (2006) stress the importance of validity since it relates to the methods, techniques, and approaches used in the research. Martin and Huntington (2012) discuss the maturation of the validity concept, which has developed from an indicator that a certain instrument is measuring what it claims to measure, to becoming a measure of honesty, richness, depth, and the scope of the data researched.

It is therefore important to note that, in quantitative and qualitative research, a degree of bias is found. This is due to what Martin and Hanington (2012) rank as the subjectivity of the respondents, in relation to their perspectives, opinions, and attitudes towards a certain subject. The argument put forward by Maxwell (1992), echoing Mishelr (1990) against Guba and Lincoln (1989), all cited in Cohen, Manion, and Morrison (2011), raised the need to replace the notion of validity with that of authenticity. In quantitative research, validity can be enhanced by careful sampling, related instrumentation, and appropriate statistical measures.

Since this research relies on a mixed-method approach, a triangulation phenomenon is evident. Campbell and Fiske (1959) cited in Cohen, Manion, and Morrison (2011, p.195) consider triangulation as a "powerful way of demonstrating concurrent validity". 'Methodological triangulation' is adopted in this study whereby different methods are used on the same object of study.

Partnering validity is the reliability concept that deals with how well the research has been performed, as defined by Blaxter, Hughes, and Tight (2006) and Bryman (2012). Cohen, Manion, and Morrison (2011) state that it is synonymous with dependency, replicability, and consistency in relation to groups or respondents. In relation to the present research, it is assumed that the SAFE value framework is a reliable tool to measure other products with cultural constraints. In addition, the possibility of Mashrabiya being 3D printed will be validated, and its economic viability will be tested.

Cohen, Manion, and Morrison (2011) also suggested that the effects of the threats to validity and reliability can be reduced by paying careful attention to their values throughout the research process. They claim that reliability can be considered a necessary precondition of validity. However, validity can be sufficient but unnecessary for reliability.

4.3 THEORETICAL ELEMENT

4.3.1 Mashrabiya 'case study' projects in the literature

The case study approach is widely used in architecture, especially historical or past project case studies. The concept was first used by Frederic Le Play in 1829 to uncover in-depth information from a variety of contexts. The fact that it is a flexible and inexpensive method, as described by Curedale (2013), has increased its popularity. The challenges of this method, however, are that the data gained cannot be generalised to several contexts. It might well be biased towards confirming the researcher's predetermined notions. But the present research uses this method because the context of the case studies is similar to that of the research context; the users are known and the benefits of gaining a framed insight into the studied case can strongly influence the research direction and conclusions.

In design, architecture, and creative research, case study research provides a starting point for concept and practice research validation. Collins (2010) defines the case study as an intensive examination and explanation of a single unit, be it a person, company, or project. It is an ideal method to research what is current and what brought it to existence. In architecture and interior design, as claimed by Martin and Hanington (2012), this method can help in understanding the design concept and outcome design in response to a given problem within a special context. The culture, climate, architectural concept, and manufacturing advancement are rich sources of not only the final visual result but also for the design process used.

The product of Mashrabiya has been a repeated feature in many great projects around the globe, such as the Museum of the Arab World in France and Albahar Tower in the United Arab Emirates (UAE). It is therefore essential to consider case studies of unique projects to be studied in detail within this research framework. The sampling and selection of cases relied on the literature investigated in Chapter 2. As a result, four case study projects were selected and examined according to their uniqueness and the perceived benefits of using them (see Table 4-3).

Table 4-3: Researched case studies and selection criteria. Source: Author.

Project name/ Case type	Uniqueness	Benefits	Difficulties
Khalaf House 1940s/ Manama, Bahrain Site-visited case study	Original Bahraini Mashrabiya type	• Scale applicable for housing size. • Shares same research context being in Bahrain, accessible. • Still existing and accessible. • Has original products of both Aggasi and Mashrabiya screens. • Built for a high-income family member. • Incorporate a high level of foreign workmanship.	• Not enough data in the literature about exact building information; mostly relied on word of mouth. • Mashrabiya construction cost not documented.
Masdar City 2009/Abu Dhabi, UAE. Literature-based case study	Unique sustainable material	• Scale appropriate for development projects. • Provides new aesthetic and environmental forms of material and pattern to produce Mashrabiya. • Design influenced by foreign culture and origami concept. • Mashrabiya used within a sustainable context. • UAE context is similar to Bahrain.	• Could not obtain any feedback from users. • Functionality and cost not proven or documented in the literature.
Albahar Tower 2014/Abu Dhabi, UAE. Literature-based case study	Use of parametric and kinetics in Mashrabiya design	• Scale appropriate for iconic buildings and landmarks. • Use of parametric design and building modelling to study possible behaviour of Mashrabiya. • Constructing new kinetic Mashrabiya that respond to weather conditions. • Modelling and manufacturing was the collaborative work of different local and international specialists.	• Building scale and budget do not match housing projects. • Pattern functionality and maintenance cost can be unreasonable in the long run.
Microclimate 2013/Conceptual Literature-based case study	Use of 3DP possibilities	• Use of 3DP as a new possible manufacturing technology. • Use of passive cooling system projected to insure product. • Mashrabiya concept used parametric algorithms to revive its pattern in a new design. • Advancement of functionality, design and manufacturing.	• Scale not applicable to 3D printing in a reliable way.

4.3.2 Mashrabiya window surveys as secondary data in the literature

Secondary research data can strongly support the primary data collected in this research. Blaxter, Hughes, and Tight (2006) value the use of secondary data in research as in their opinion it makes sense to use it if it already exists in some form. Their claim is that secondary data can complement primary data collected by the researcher. The fact that secondary data may also modify, confirm, or contradict primary research findings makes it a critical argument that it should be included in the research. Isolating the PhD research from other studies in the field should be avoided, as building rich resources that support the aim and claim of research findings is always favourable.

Hariri (1986) advised that survey research and the data gathered from it is a vital element in social science research and architecture. The importance of understanding how Bahrain's residents rate window treatments is essential to this study. By understanding the values that relate to window treatments and shading selection, the research can build its argument and enhance its importance.

The market survey of this research was highly dependent on an earlier investigation survey by Aljawder (2014) for results. As Aljawder (2014) investigated the relationship between visual privacy and daylight in Bahraini homes, Mashrabiya was her focus. However, a lack of estimates of prices and comparing manufacturing possibilities may be claimed to be the missing points in Aljawder research, which is a gap filled by this report.

Another researcher, Sidawi (2012), also conducted a survey on the subject of Mashrabiya in Saudi Arabia, Bahrain's neighbouring country. His data and criteria were also taken into consideration as secondary information when conducting this research survey.

4.3.3 General public survey

The self-completed questionnaire is a type of questionnaire defined by Bryman (2012) as one that is completed by the respondents themselves. This type of social survey design can help in gathering data from a large number of respondents. It is used in the present research to support earlier data collected from the literature (Sidawi, 2012; Aljawder, 2014) and helps to predict current market preferences and aspirations in Bahrain.

The benefits of such a method are evident in its quick administration time, the absence of the effect of an interviewer upon the respondents, and its low cost. Another benefit of this method compared to the interview method is the limitation of the interviewer's variability to answer questions, and that it can be conducted at a convenient time for the respondent.

However, Bryman (2012) also highlights some disadvantages that should be taken into consideration. These include the researcher being unable to help the respondents by prompting, probing, or collecting additional data, hence minimising the number of questions and the appropriate nature of questions asked to different respondents. Another concern is evident in the fact that people vary in their facility with computers and some may not be ready to participate in an online survey or may consider the email invitation as being merely another junk email. There are also concerns relating to information confidentiality. Therefore, there is a greater risk of missing data and receiving a lower response rate – or getting data, but not from a representative sample. A group of Bahraini locals and residents was approached, based on the main population data size. It was decided that an online survey would be conducted in May 2014. The aim was to ensure ease of access and a fast response rate, built upon the known availability of smart devices around Bahrain.

Two surveys were conducted. The first aimed to measure 3D printing awareness and Bahraini locals and residents' familiarity with the 3DP technology. This survey was distributed to 30 participants of Bahrain first 3D printing and additive fabrication workshop held on August 2013. The second was the survey conducted in May 2014 and was chosen to be an online one. The aim was to measure public awareness to windows function, preferred aesthetic form, customisation preferences and purchasing power. It was chosen to be an online one to assure easiness of access and a fast response rate, built upon the known availability of smart devices around Bahrain. Please refer to appendix D for a response sample. The survey questions were kept short and to the point, as advised by Collins (2010), with a total of ten questions. Respondents were expected to be able to complete the questions within 5–8 minutes so that the survey would be suitable to complete on digital devices and social media applications like WhatsApp (a link for the latter was distributed alongside the email invitations). An Arabic translation of the survey questions was made available in addition to the English questions to ensure a better understanding of the questions asked.

The validity and reliability of the questionnaire followed the suggestions of Cohen, Manion, and Morrison (2011) in terms of the time spent completing the questionnaire, ease of completion, sensitivity of questions, and their length. The researcher's familiarity with the nature of the sample population also helped in obtaining effective responses.

4.3.3.1 RESEARCH SAMPLE AND SAMPLING METHOD

In research practice it is a known fact that the method used to sample the population is an essential aspect of gathering viable data. The sample size for the Bahrain population of 1,318 million people was calculated at 193 respondents, with the confidence level of 95%. The entire targeted sample of the second survey was of Bahraini and non-Bahraini persons living in Bahrain and with different backgrounds, religions, income, and housing type.

As undertaken and validated by Aljawder (2014), Krejice and Morgan's (1970) method for sampling calculation was used for Bahrain, as shown in Figure 4-2. The figure describes the number of respondents needed for the Bahrain population according to the 2014 population statistics.

Sample Size for Given Precision

Confidence Level:		80%	90%	95%	99%
z-score:		1.2816	1.645	1.96	2.5758
Precision +/- =	5%	What is my sample size?			
Population Size =	1,318,000,000				
Assumed P =	90%	60	98	193	239
Conservative P =	50%	165	271	385	664

Figure 4-2: Sample size calculation based on Krejice and Morgan (1970) for Bahrain.

$$\textit{Sampling error} = \frac{1}{\sqrt{N}}$$

Where N = sample size.

Figure 4-3 - Czaja and Blair (1996) sampling error formula

Figure 4-4 (taken from Czaja and Blair, 1996) was used to calculate the sampling error. The sampling error was calculated to be 0.0792 for the 193 survey respondents, which can be considered average for the sample size of the survey. The same method has been used by Aljawder (2014) with her Bahraini-targeted population.

4.3.3.2 PILOT SURVEY

As noted by Bryman (2012), piloting has a major role in ensuring that the questions and the entire research instrument operate well. It was also used to determine which questions prompted respondents to answer in the same way, as this might predict insignificant results. A pilot study survey and interviews with 30 possible respondents helped in adjusting a few of the misunderstood questions. Moreover, it was found that the survey demographics were filled in by respondents if they were kept until the respondents had covered at least 80% of the questions. This was crucial, as one question was related to monthly income, which might have not answered in a face-to-face survey or if the question had been provided at the beginning of the survey.

4.3.3.3 THE INTERNET-BASED SURVEY

Cohen, Manion, and Morrison (2011) state that using the internet to conduct surveys is starting to become more and more common every day. Internet-based surveys have gradually changed from being in email form to an email with attachments to an email with a link to another website. Web-based surveys are advisable nowadays as they not only attract more respondents but also reach respondents were are located a long distance away from the researcher's location.

The survey questionnaire was conducted online using a web-based service, SurveyMonkey. The link to the survey was then distributed via social media websites and apps to be completed by Bahraini locals and residents. The online option was used because the majority of the participants used smart phones. The survey was designed therefore to fit their screens and be finished in less than 8 minutes.

This survey was initiated as a 'testing the ground' tool to investigate initial housing types and preferences for window shading device types with SAFE indicators. This was also important as it indicated people's preference regarding pattern types and the amount they would be willing to pay for such a product. The survey protocol used is documented in Appendix C.

Table 4-4, following the recommendations of Allu (2014), explains how each question was formulated to meet the research aim and objectives. The full questionnaire can be viewed online, and a sample response printout is provided in Appendix D. A selection of the main guidelines referred to by Cohen, Manion, and Morrison (2011) based on Dillman et al. (1999) was taken into consideration while designing the questionnaire:

1- The survey words count can negatively impact the reader and thus it was kept to its minimum without branching information or instructions.
2- Large fonts, templates, and translations of the questions in Arabic were used to aid the readability and comprehension of the questions.
3- The line length was kept short to fit the mobile screen size.

Table 4-4: Survey questionnaire data, rationales, and analysis. Source: Author.

Q#	Questionnaire/ Themes	Purpose/ Data Type	Rationale		Non-parametric Analysis and Test
			Research Initial Objective	Research Question	
1	Type of housing	Architecture housing type Ordinal data	E	Basic info	Descriptive analysis
2	Number of rooms	Window number data	E	Basic info	Descriptive analysis
3	Housing ownership type	Testing level of ownership with preferences of facade treatments	E	Basic info	Statistical analysis
4	SAFE ranking of windows	Evidence of SAFE impact on selection, ordinal data	C, E	i	Descriptive analysis
5	Other factors affecting selection	Further factors not included in SAFE	C, E	i	Descriptive analysis
6	Standard vs personalised window design perforation	Ordinal data about window preference	E	Design info	Statistical analysis
7	Preferred pattern type	Aesthetic data to guide prototype	H	Design info	Statistical analysis
8	Personal windows categorisation	Aesthetic preference, ordinal data	H	ii	Statistical analysis
9	Possible price to pay for personal windows treatment	Window shading budget ratio data	C, F, G	ii	Statistical analysis
10	Monthly income	Social rank ratio data	C, F	iv, vi	Statistical analysis
11-14	Demographics: Age group, nationality, religion	Demographic ratio and nominal data	C	Basic info	Descriptive analysis

Table 4-4 shows that some questions were inserted to gain basic information and feedback from the general public and may not be directly related to the research questions. However, an understanding of the current trends and users' preferences was needed in the first phase of this research data collection. Furthermore, the online survey aimed to obtain information that could further influence the next phases of this research. The question of desired shading devices design, for example, helped in making a decision regarding the shape of the Mashrabiya to be parametrically designed for 3D printing, although the cost a user is willing to pay for a personalised and customised window shading treatment can highly affect the future cost range of accepted 3D-printing product prices.

The most important question in this survey was question 4, which asks respondents to rank the SAFE values; the results of this question were compared to the previous literature and other data to confirm or contradict its hypothetical value.

The response rate was considerably high in relation to the 2 week time period in which the questionnaire link was available. 193 respondents answered the questions from different fields and nationalities residing in Bahrain.

4.3.3.4 STATISTICAL ANALYSIS

The statistical analysis needed for this survey was minor, as the survey mostly examines trends in design which can be considered more as qualitative rather than quantitative data. An appropriate analysis was recommended by the statistical analysis specialist at the DMU Math and Learning Centre.

Table 4-4 also indicates the type of data gathered for each question and accordingly the best type of analysis to be used. In addition, using an online-based service like SurveyMonkey helped in automatically collating and presenting the results in order to inform the next phase of the research. More detailed information of each survey is further presented in Chapter 5.

4.3.3.5 ETHICAL REPORT

During March 2013 the ethical committee in the Art, Design, and Humanities Department at De Montfort University granted its approval to conduct the research survey and interviews. The survey respondents were assured that their participation would be anonymous, and that all data provided by them would be used for academic purposes only. Interviews with professionals and manufacturers were completed voluntarily and willingly with their given consent to participate in a digitally recorded way or via Skype interviews, emails, telephone calls, or face-to-face meetings. Methods other than face-to-face interviews were more practical and reliable as well as convenient, as participants were located at a distance from the researcher unless interviews were performed in Bahrain by the researcher. Therefore, all data used in this research were ethically obtained and legally permitted.

4.3.3.6 VALIDITY AND RELIABILITY

The questions and translation were found to be reliable and valid by other bilingual PhD colleagues in Design and Architecture as well as by my supervisor. It can be claimed that the survey was validated by peer review, by native speakers of both languages used within the questionnaire. The validity and reliability of the online questionnaire against the postal questionnaire was based on Cohen, Manion, and Morrison's (2011) recommendations. The postal questionnaire was neglected by the researcher since postal letters are mostly a one-way service in Bahrain. The majority of the locals do not use postal services and rely on emails and fax instead.

4.3.4 Interviews

Obtaining information about the latest conceptual designs and manufacturing techniques required regular visits to manufacturers' shows, exhibitions, and workshops. During visits, the researcher used a combination of semi-structured interviews and unstructured open interviews to gain the required data. Good networking skills and time management were key drivers in conducting these interviews. See Figure 4-5.

A variety of methods were used to conduct the interview, including face-to-face interviews, email, telephone, and social media messages. The form varied according to which method best fit the resources, the time slot, and the availability of the interviewee in the new digital age of smart phones and apps. Interviews questions are listed in Appendix E.

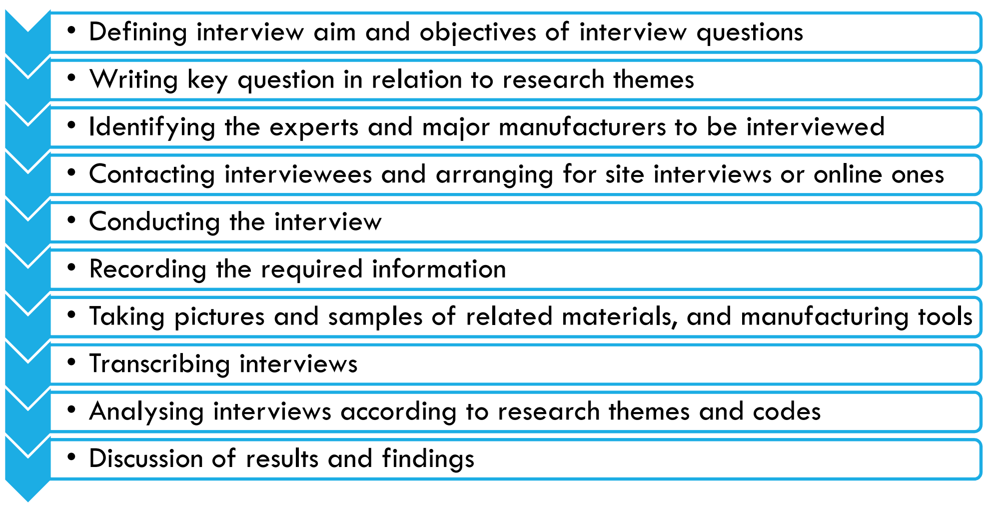


Figure 4-5: Semi-structured interview protocols. Source: Author.

The reliability of the interview method remained constant, as most questions asked were dealing with cost figures and manufacturing facts or architectural phenomena and social observations. During the manufacturing interviews, open-ended questions and long discussions sometimes occurred. The researcher, however, attempted to divert the discussion back to the aims and objectives of her research when possible. Due to the different categories of interviewee, as will be explained next, the question type and response rate varied. Some interview answers were ignored if they fell outside the research's SAFE context. During conference participation and manufacturing shows, unplanned interviews took place. One or two questions were raised in such interviews. Taking advantage of such opportunities, quick questions where practical were asked, although not necessarily abiding to the protocol defined for most of the semi-structured interviews conducted.

ACADEMIC INTERVIEWS

The researcher had planned a set of initial interviews in the first year of the research (2013). The aim of the initial interviews was to investigate possible gaps in people's knowledge and the need for novel research ideas in relation to Mashrabiya. Five academics from the University of Bahrain, and two from Kingdom University in Bahrain were interviewed.

The researcher also relied on recent PhD theses about the Mashrabiya and looked into the researchers' future possible work. Based on their relevance, the researcher initiated contact through personal email via the academia.com website and the LinkedIn professional social networks were used to discuss her ideas and to benefit from academics' views towards the subject of this research. Academics were found to be more capable of speaking about the social, environmental, and design implications of the Mashrabiya. Minor knowledge of the cost and manufacturing options was found, which pushed the researcher to interview market manufacturers and architects to fill the gap in comprehending the Mashrabiya as a product.

The later stage of academics' interviews was conducted in late 2014 and 2015 in a face-to-face and email interview type. Interviews targeted 30 academics from architecture and the interior design department, but only nine responded. The low response was due to work commitments. The interviewees were from different nationalities but were familiar with the product and the context.

The interviews were of a structured type and were online-based. The questions followed themes that had emerged from the literature gaps found. They were categorised into the following topics:

A. Social and economic drivers affecting traditional and current Bahraini houses

B. Factors affecting facade treatments and shading devices

C. The aesthetic and design solution dominating current housing facades and window treatments

D. Prioritising the function of windows in Bahraini houses, and reflections on selecting shading devices

E. Extent of economic factor, material cost in selecting facade and shading treatments in Bahrain.

The six questions asked within these themes were relevant to the initial aims and questions of this research.

The ongoing benefits from speaking to academics about the subject area were evident in the progress of the researcher's work through the duration of her PhD course. The subject and the approach were also presented on several occasions outside and inside the DMU. Positive feedback about her approach and critical comments on the context and methodology were gained from participating in the following events:

1- DMU Poster Design competition, April 2014 and 2015, Leicester, UK
2- DMU Research and Design Group monthly talk, March 2015, Leicester, UK
3- University of the Creative Arts Talk invitation, April 2015, Canterbury, UK
4- Initiating and being a member of the DMU Design Research Group, where peer review comments are gathered in context and the methods implemented, June 2015.

More details about the activities listed and their benefit to research progress can be found in Activities blog Appendix F.

ARCHITECTS AND DESIGNERS INTERVIEWS

Curedale (2013) suggests that the use of contextual interviews can unleash tacit knowledge. Interviewing architects and designers can give an insight into people's needs, design interests, budget, and market trends. However, getting architects who meet the right criteria can be a challenge. The total number of architectcs interviewed was 9 architects and 3 designers.

Methods-wise, online-based interviews were combined with face-to-face interviews to obtain architects' input to the research context. This method provided extended access to people, as it allowed architects the chance to answer the questions at their own convenience within their busy schedules. This method also saved notes and transcription time and arranging a convenient meeting time also saved time.

A semi-structured approach was used in conducting most interviews. It also became clear that there was a need to conduct unstructured interviews, especially after conference presentations or manufacturing exhibitions. There, the researcher engaged in an open discussion, which is determined by the interviewee's initial reply to the researcher's question, as stated by Collins (2010). A more selective approach for conducting the online interviews used a social network known as LinkedIn. This had benefits for choosing interviewees that fit certain criteria, since it provided a professional CV, explicit background information, and details of relevant experience. The method also allowed the researcher to benefit from contacting both local architects, and regional and global ones. It also allowed the researcher to add them to her network for any future need to add or amend questions and gain feedback. The selection criteria are outlined as:

1- Minimum of 3–5 years' experience in the professional field of architecture practice.
2- Possible knowledge about Bahrain and the MENA region market and trends.
3- Possible knowledge about parametric design and 3D printing.

The researcher benefitted from attending the following events in networking and getting a general feel about the subject of interest. Building her own network, further in-depth interviews with a selected audience were then initiated in relevance to the topic. The events are outlined in Exhibitions and conferences as well as activities blog listed in Appendix B and F. Here is a selection of these events:

1- 4th Energy & Water Conservation Expo & Forum, June 2013, Manama, Bahrain
2- 1st Energy Management Conference and Exhibition, December 2013, Manama, Bahrain
3- Façade and Design Engineering Summit, September 2014, Dubai, UAE.
4- ASA International Conference, December 2014, Genoa, Italy.
5- Design Principles and Practices, February 2015, Chicago, USA.
6- 4th International Architecture Heritage Conservation, February 2016, Dubai, UAE.

The questions aimed at architects and designers fall under the previous themes as the interviews with academics, with the addition of the following themes to triangulate data in the field and market:

- Role and capabilities of manufacturers in producing shading types
- Customisation abilities of Bahraini market manufacturers
- Window shading codes, standards, and specifications of large real estate development projects
- Current architecture and window treatment trends in residential houses.

MANUFACTURERS INTERVIEWS

Semi-structured and unstructured 19 interviews were conducted during meetings with professionals in both the additive manufacturing industry (12 interviewee) and with the wood and GRC manufacturers and craftsmen (7 interviewee). The term 'manufacturers' is used here to describe manufacturers specialising in 3D printing or managers in wood manufacturing plants. Expert salespeople representing the manufacturer in exhibitions were also considered within this category.

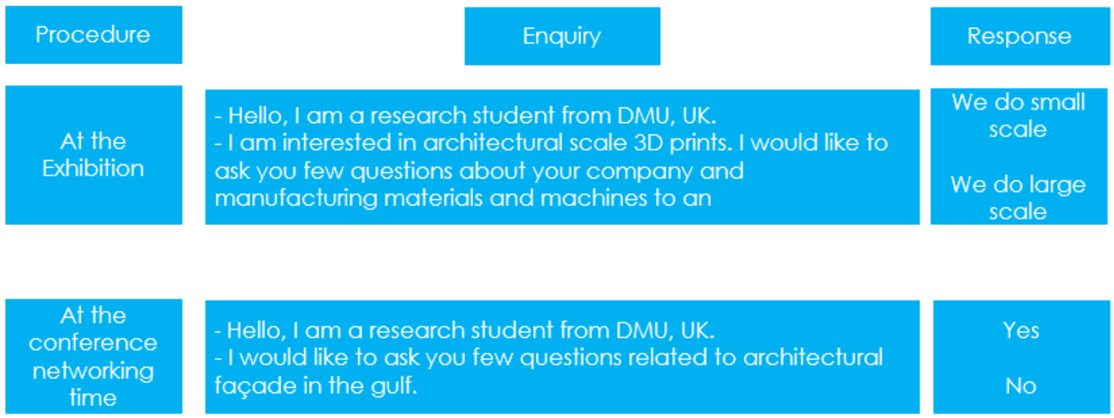


Figure 4-6: Standard Operating procedure (SOP) for interviews – Exhibitors and conferences presenters' example. Source: Author.

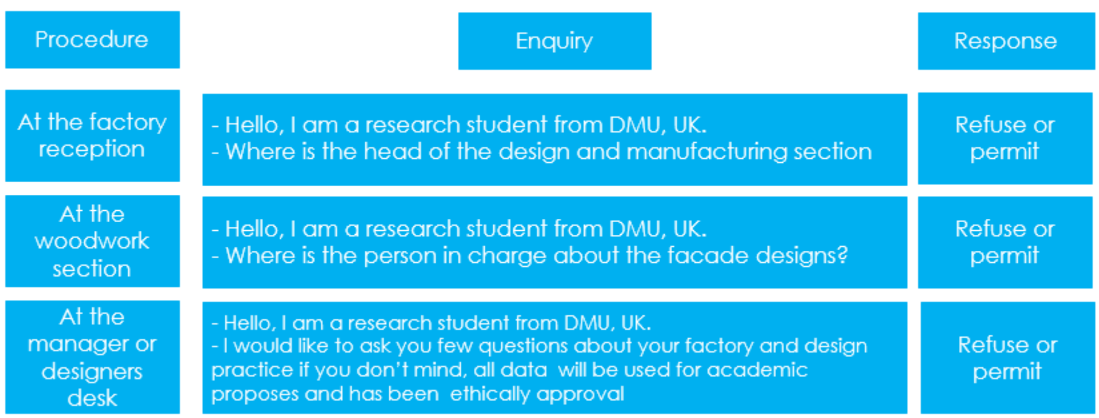


Figure 4-7: Standard Operating procedure (SOP) for interviews – Manufacturers example. Source: Author.

Figure 4-6 and Figure 4-7 represent the Standard Operating Procedures (SOP) followed while conducting this category of interviews. Two sets of manufacturers interviews were conducted depending on the research phase and information needed.

Limited time and recording quality were challenges faced in this interview category. However, online-based interviews using LinkedIn overcame this challenge. 3D-printing specialists were contacted and invited to participate in these interviews, emails were sent, or telephone and Skype calls were arranged afterwards.

The researcher benefitted in this task from the range of 3D-printing groups available on LinkedIn, as well as semi-structured interviews conducted while attending the following exhibitions (explained in the Appendices):

1- TCT Show, Birmingham, September 2013.
2- Engineering Design Show, Coventry, November 2014.
3- Develop 3D Live, Coventry, April 2015.
4- TCT Show, Birmingham, October 2015.

4.3.5 Feasibility study and economic modelling

To understand the economic viability of a 3D-printed Mashrabiya screen, the researcher had to obtain several pieces of data. The cost of the current Mashrabiya if made of wood or GRC should be compared to that of a 3DP Mashrabiya. Only Aljawder (2014) had hinted at the general cost of wooden Mashrabiya in her research.

Information on the additional costs of transportation, labour, maintenance, and materials was needed. Furthermore, the cost of large-scale 3D printers was also compared against their availability and development. The researcher relied on the Wohlers Report in this matter, comparing data and prices between Wohlers' 2014 and 2008 versions to look into trends, costs, and price variations.

The researcher also relied on manufacturers' catalogues and websites to accumulate data related to the cost of machines and large-scale 3D printers.

A feasibility study run by Ahmadi (2014) presented some of the data needed in setting up a Fab lab and introducing fabrication technology to Bahrain. His study will be considered as secondary data to support 3DP Mashrabiya.

'Economic modelling' was also an emerging key word recommended by the economist interviewees included in this research. A proof-of-concept cost was compared with several large-scale 3D printers to gain an idea of the possible price.

4.3.6 Focus groups

Falling under the scope of qualitative methods, Kmeger and Cassey (2000) defined ‘focus groups’ as prearranged meetings with targeted individuals. Bryman (2012) emphasised the importance of focus groups on a specific theme or topic that can be investigated in depth, in contrast to group interviews in which the subject can vary widely. The benefits of focus groups are also evident in terms of saving research time and money by collectively listening to opinions from various individuals in one place (Bryman, 2012). The targeted individuals or participants, as explained by Kmeger and Cassey (2000) and Bryman (2012), may express and discuss certain issues as a member of a group rather than as an individual interviewee. This can highly benefit the research as individuals may share ideas and respond to each other’s’ thoughts and build upon them.

From a research point of view, this can help in identifying trends and gaps as well as identifying leaders and thought-provokers. Another benefit of focus groups recorded by Bryman (2012) is that they are a means of challenging individuals’ thoughts, through participants arguing with each other. This can clearly allow a researcher to obtain a better insight into the subject and gives the opportunity of resulting in a more realistic view of the raised subject, as highlighted by Bryman.

The researcher relied on two types of focus groups. One was dedicated to professionals and academics working within the subject of this research, while the others were arranged to include possible Bahraini local or resident end users who might be interested in owning a 3DP Mashrabiya.

Figure 4-8describes the Standards Operating Procedure (SOP) used in conducting the focus groups with reference to Curedale’s (2013) steps:

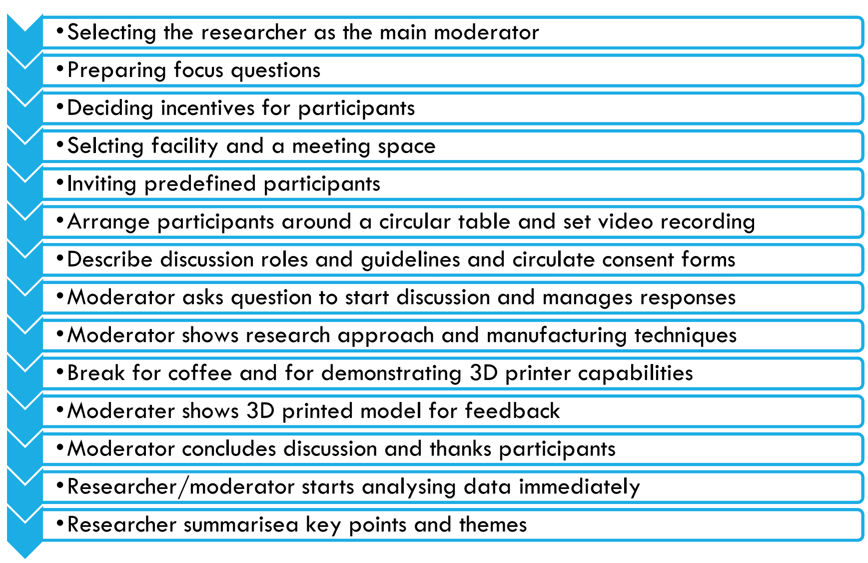


Figure 4-8: Focus group (SOP). Source: Author.

A consequence of 'group effects' may be a possible problem and limitation of this method, as noted by Bryman (2012), if experienced participants were to lead the conversation and other members were to follow them.

A.PROFESSIONALS FOCUS GROUP

A meeting with several people from architecture, interior design, academia, and the Bahraini manufacturing market's wood and 3D-printing experts was arranged to take place on 14 June 2015. The group consisted of 6 members.

The arrangement of a suitable time and venue was an initial problem but this was overcome by delaying the meeting to accommodate all professionals during an evening time slot after participants' working hours. 6.30–8.30 p.m. was the time chosen but unfortunately due to the late arrival of a few members, that meeting started at 7 p.m. The venue chosen was at the showroom of KB Proto, Bahrain's first 3D-printing company, which was suitable for demonstrating the technology in action.

The aim of the first focus group – with the professionals and academics – was to gain feedback on particular research themes and the proof-of-concept model developed after the initial market survey. Academics in both interior design and architecture are considered the main respondents for giving information about college graduates and future architects and designers of facades and their treatments. It also may be considered equally important to hear the opinions of manufacturers of local and regional material suppliers of architecture and housing facades in terms of shading devices and current market trends.

The aim was also to obtain feedback on the proof-of-concept model developed and 3D printed to demonstrate the technology capabilities and the design potential in hand. Milton and Rodgers (2013) suggest that a product of interest can be used in the discussion to gain feedback and insights. Questions and prompts were designed to avoid drawing a particular response to the research interest to ensure the data gathered was not biased.

The thematic discussions and topics initiated in the meeting responded to the SAFE values defined earlier. The following chart represents the topics discussed at the first focus group meeting and the time slot scheduled for each topic to maintain good control of the time and flow of the meeting. The total duration of the meeting was estimated at 2 hours, with a 10–15-minute break in between.

The meeting began by showing slides of images that best reflected the research context and gaps to stimulate the discussion, followed by 3DP model samples that would be seen and tested manually in order to obtain feedback at the end of the session. See Figure 4-9.

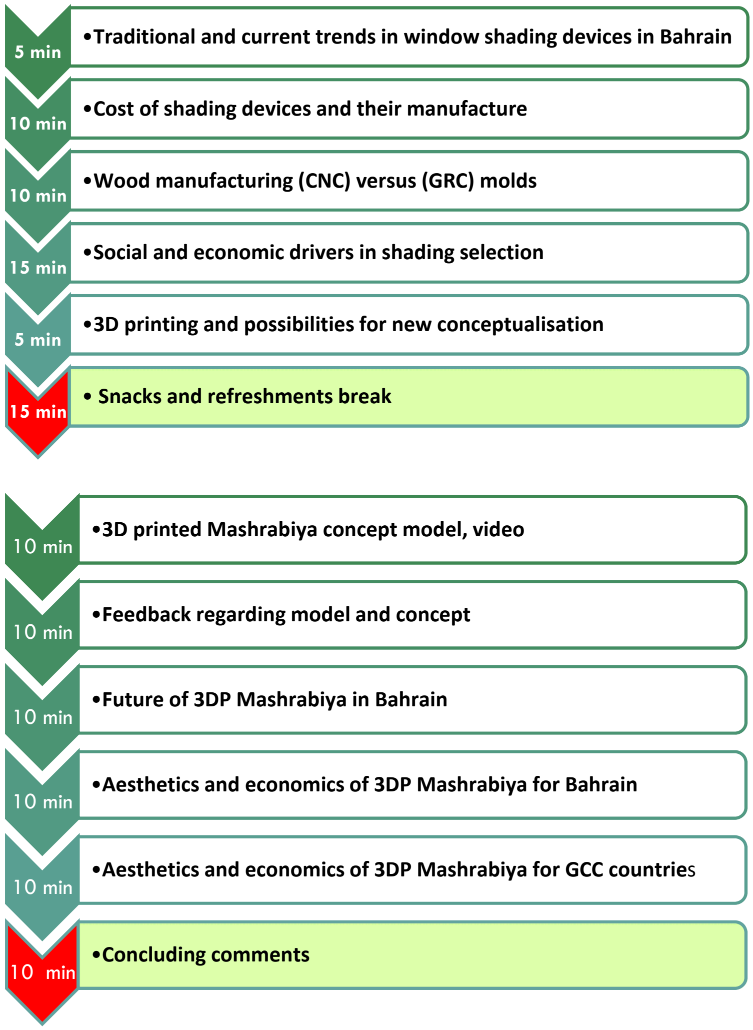


Figure 4-9 Professional focus group steps. Source: Author.

The recording and transcription of the focus group data was of high importance, as stated by Bryman (2012). Video recording was chosen as it would have taken too long to write notes to keep up with the flow of the group discussion and the participants' views. Video recording also helped in understanding the visual feedback and the conceptual empathy towards the discussed product.

The limitation of the method was evident regarding the difficulty of data analysis, as a huge amount of overlapping data was quickly produced. The data transcription method relied on focusing on the important parts of the discussions and not transcribing everything, as breaks and side discussions were ignored by running video-editing and clipping. Three hours of recording were edited down to 1 hour and 52 minutes of constructive discussion.

Figure 4-10: The professional focus group sitting in discussion and the proof-of-concept model in evaluation. Source: Author.

B.POSSIBLE END USERS FOCUS GROUPS

Martin and Hanington (2012) recently published their 100-ways to universally design methods books. A fair number of methods described in the book targeted the design of products and their prototypes. Obtaining fruitful feedback about a design object plays an essential role in its development and functionality before unleashing and marketing it. Evaluation research, desirability testing, focus groups, Kano analysis, prototyping, semantic differentials, and value opportunity analysis are some relevant examples of methods used in this research. However, it was a difficult and vast task to perform all of these methods to test the validity of the new 3DP Mashrabiya. Therefore, a small number of representative individuals were selected to take part in focus groups, and Martin and Hanington's (2012) methods were integrated within the questions put to those group respondents.

The Bahraini general public was counted as the end users of or respondents to the 3DP Mashrabiya proposed in this research. The SAFE values were therefore best scaled according to the responses of that group. The researcher assembled several mini-groups of individuals who were Bahraini locals and residents to comment and discuss the proof-of-concept model generated in phase two. The criteria for participant selection depended on the age, ownership of dwellings, and involvement in design decision-making concerning the facade selection process of future or existing owned houses.

Young couples were grouped with designers or average Bahraini residents to gain feedback in a photography-led discussion. Realistic rendered photographs of the modelled screen were presented to ten groups of around 4–6 participants each. A total of 42 (above 20 years old) male and female participants' input was gathered. Multinational face-to-face groups were conducted alongside online focus groups via a live chat application, see Figure 4-11.

The benefits of using this method, as noted by Curedale (2013), are its usefulness in gaining different viewpoints about the designed object and the research behind it. It is also beneficial in identifying expectations and limitations as well as the possible tastes of people in Bahrain. A disadvantage of this method is the bias caused by individual participants influencing each other's opinions.

Figure 4-11: Face-to-face focus group with multinational residents. Source: Author.

4.4 EVIDENCE- BASED PRACTICE ELEMENT AND THE DEVELOPMENT OF 3DP MASHRABIYA (3DPM) AS A PROOF-OF-CONCEPT MODEL

4.4.1 The range of evidence-based research

Practice-based or practice-led research is commonly and problematically considered by Niedderer and Roworth-Stokes (2007) and Biggs (2005) as an umbrella of methods used to bring artistic creativity or design practice to academia, while evidence-based research is more involved with what curators and designers produce as a result of their research in the field of their practice. This research not only develops a holistic approach to the design of an old archetype to a new one, but it also considers the creative and new possible forms that it may take as a 3DPM product. Therefore, part of this research really falls into the class of evidence-based research, since there is an artefact or a model that is produced as a result of the research that is adopted and used as evidence to prove the theoretical claim of the research questions.

Looking at other scholars' and architects' creative forms of the Mashrabiya generated based on intensive research is an example of evidence-based research results. The term 'practice-based research' overlaps with evidence-based design in the context of this research. An investigation of the role and the use of creative practice in research were conducted by Niedderer and Roworth-Stokes (2007). They ran a Google Scholar search on each of the terminologies used within creative practice research and contribution to knowledge, and the following results indicate how vast the field of evidence-based research is:

Term	Hits (no qualifier)	Hits (qualifier: art & design)
Research	29,900,000	8,730
Practice-led research	66	24
Practice-based research	2,530	135
Arts-based research	12,800	300
Design-based research	27,200	113
Studio-based research	24	24
Practice-centered research	24	24
Critical inquiry	19,600	164
Investigative practice	246	3
Reflective practice	18,700	269
Evidence-based practice	28,700	54
Research informed practice	166	0
Research-led practice	20	0
Practice	8,560,000	6,970

Figure 4-12: Niedderer and Roworth-Stokes' (2007) investigation into the art and design research terminology on Google Scholar.

The need to legitimise a methodology in the creative industry's theoretical and practice research has been sought by scholars like Park (2005), Sullivan (2005), Saikkaly (2004), and Biggs (2002), cited in Niedderer and Roworth-Stokes (2007); see Figure 4-12.

The following research stages represent how the design part (practice) of the new 3D-printed Mashrabiya was undertaken.

THE FIRST STAGE

During 2013 initial interviews were conducted to obtain a general understanding about the Mashrabiya as a product and its social and functional benefits. Its design challenges and costs were also investigated. The possibilities of 3D printing and additive manufacturing in enhancing the Mashrabiya as a product were evident from the literature review conducted. However, 3D printing was in its infancy in Bahrain at the time, with only one shop in Bahrain (opened in April 2013) that had just started its business in supplying 3D printers in the market and region. Awareness of the technology and the introduction of its possibilities were beginning to reach the general public by the KBProto company founders. A workshop dedicated to artists and designers was run in August 2013 at the American Art Space in Bahrain and attended by the researcher, who encountered the first unveiling of the possibilities of the technology and 3DP cultural awareness. The researcher distributed a quick paper-based questionnaire to the participants to gain general feedback about the awareness of the participants of the technology and its background.

By reviewing the literature it was evident that social demand was a key driver in reinventing the Mashrabiya in different forms and materials. A lack of aesthetically captivating designs was noticed in the Bahraini market. Looking into the practice and craft of Mashrabiya making was a key theme of the first phase of the research. The researcher increased her awareness of possible techniques and current manufacturing materials and workshops and looked at the obstacles and drawbacks of each type of manufacturing technology by interviewing people from the carpentry workshops and GRC craftsmen. The design process itself was taken for granted to be a copy/paste image of the traditional Mashrabiya that appeared redundantly in modern structures and housing units to represent a nostalgic image of traditional Bahraini houses.

By understanding the social and functional domains of the Mashrabiya, the researcher needed to understand the geometry and patterns that had once influenced the window product. Schematic designs and illustrations of scale and proportion jointly resulted in a new form of Mashrabiya based on the preferences of forms gained from the general public survey's responses.

THE SECONED STAGE

A proof-of-concept model came to shape in the second stage of this research. Several forms and concepts had been investigated in a trial-and-error cycle to reach a coherent design. Headley (2014) describes this as a '*design grotesque*', a normal phase that prototypes and products go through before reaching their final form.

The first concept was to create a complex geometric pattern based on the algorithms and mathematics of traditional Islamic patterns used in Arab/Islamic architecture. The square in its static and rotated 45-degree shaping a very common Islamic motif was selected as a base for the new model in the first trial. The added value was that the screen had a two-sided scale of the pattern to meet interior-scale requirement with a dense pattern in the interior and more open to the back. A more enlarged scale of the same pattern appeared on the exterior face to match its larger proportion to the facade.

The model was designed in 3DS Max and then 3D printed by a DMU SLS machine. The visuals seen in Figure 4-13 describe the first model. This was shown to wood manufacturers who claimed that they had the ability to manufacture this using CNC routers, even if it would be a minor challenge and time-consuming. However, the challenge was not met and 3D printing of such a model could not overcome the abilities of standard manufacturing. A need for a more complex geometry and imbedded functionality was evident.

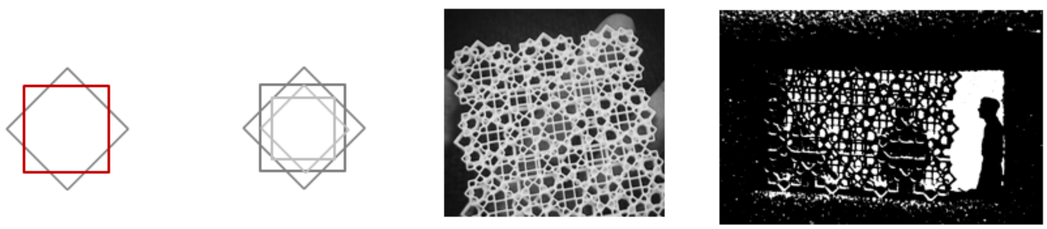


Figure 4-13: Model trial 1 based on a varied scale of an Islamic square pattern.

The first trial concept was enhanced after manufacturer's interview to enhance it into a new design approach that cannot be reproduced via CNC. The 2D screen needed another dimension to increase functionality, and to empower the aesthetics of 3D printers. The 2D square couples were linked to another square in the third dimension. The interlaced concept of a model with interwoven internal elements was a new challenge of the Mashrabiya digital pattern unit designed in 3ds Max. The visuals shown in Figure 4-14 explain this better. The idea of perforating the shell of the pattern was thought to reduce the amount of powder used but a problem of extracting the dust from within the enclosed interlace was a problem faced, leading to the idea being abandoned.

Figure 4-14: Model trial 2 based on interwoven squares on three axes modelled in 3ds Max.

Designing for 3D printing is not as easy as the media claims. Designing for large-scale 3D prints was another problem faced at this stage. The model had to be designed in collaboration with

Dustin Headley, from Kansas State University, using a parametric algorithm defined in Grasshopper and modelled in Rhino software, of which the researcher had limited knowledge. The first print using the Form 1 3D printer to visualise the model failed to print due to the form structure and the printer base, seen in Figure 4-15.

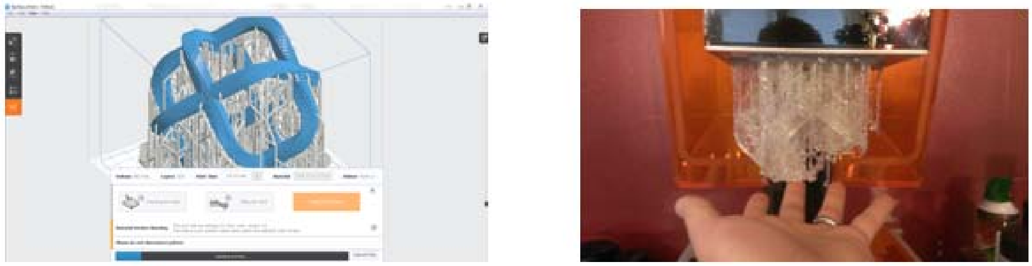


Figure 4-15: Model trial 3 redesigned in Rhino but failed to print (Headley, 2014).

The third trial concept investigated the two overlapping squares as a repeated parametric surface. The design is based on the line between the veil and its fluid movement and Mashrabiya. Creating a screen that is not necessarily flat was an added value of using a 3D-printing tool with Rhino and Grasshopper parametric modelling. Unfortunately, the finished product of the basic element was not very appealing as hard edges appeared in the finished sample.

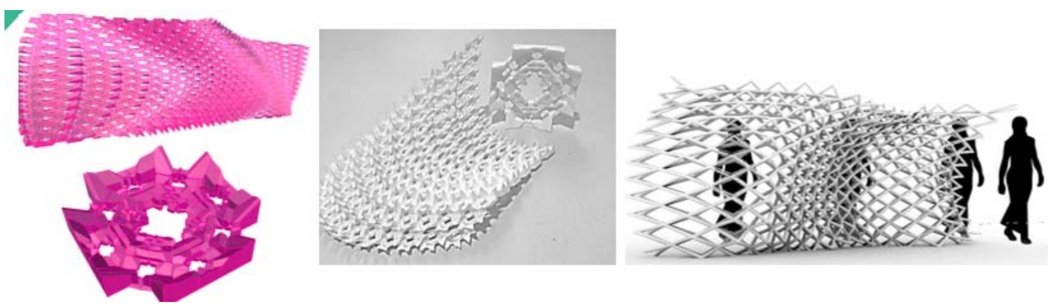


Figure 4-16: Third trial showing the fluid screen form related to the veil textile concept. Source: Author.

The fourth and final test utilised a form based on the six-headed star Islamic pattern, yet interlaced them in the third dimension (Figure 4-17 and Figure 4-18). The 3DPM screen was programmed to vary in the complexity of interlacing and the complexity of its form according to the need for visual privacy. For example, the screen needed to be denser in the middle part to veil women more, while less complex in the upper part to allow light to penetrate the interior. The definition provided by Headley was based on the privacy visual heights recommended by the researcher after her literature review findings.

The same 3DPM SLS form was used to later generate a sand model by ExOne Company as a final fifth stage. The final partial sand model is about (H30, W40, D 10cm) using S-Max 3D printer. The sand model was produced in March 2016 after the advancement on the printers and material possibilities to undergo an infiltration process. Although sand casting is used for moulding, the possibility of using it to produce final product part is investigated within a Mashrabiya screen application.

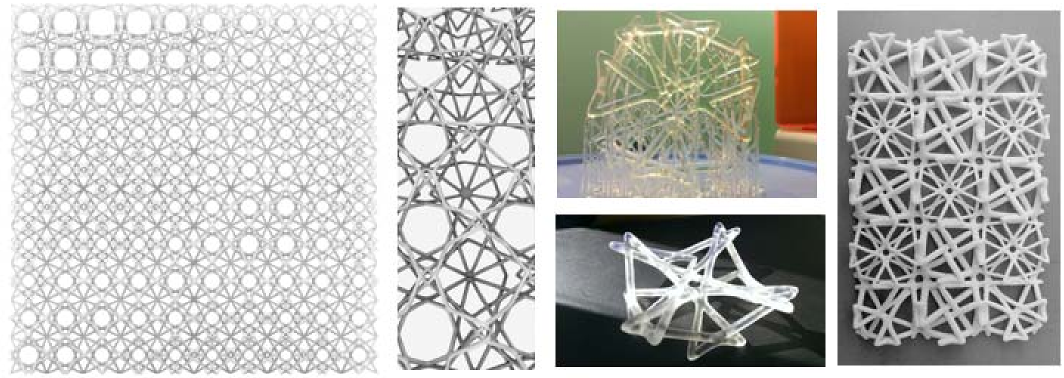


Figure 4-17: Fourth and final 3DPM screen model and trial 3D prints. Source: Headley et al. (2015).

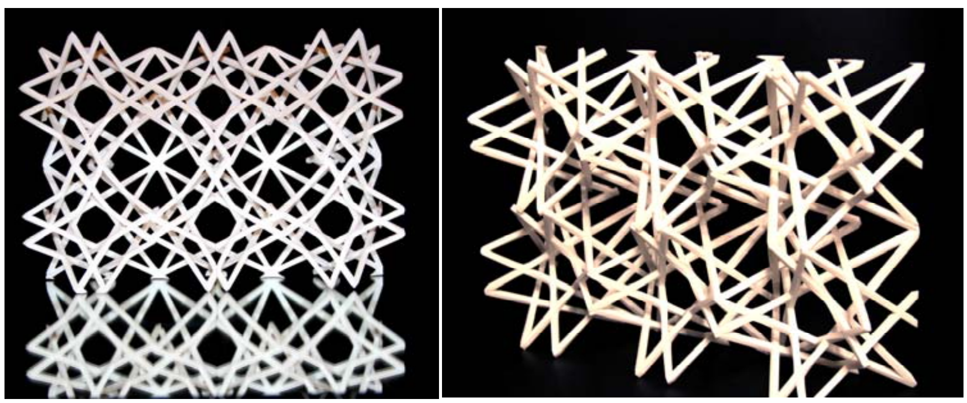


Figure 4-18: The 3DPM printed SLS partial model in real scale size. Source: Author.

THE THIRD STAGE

Having the handmade model and information on its cost made the theoretical concept a proven one. The researcher needed to get feedback from specialist manufacturers and possible end users. The two types of focus groups explained earlier were provided with the 3DPM model and the visuals of it (Figure 4-19 and Figure 4-20). This helped the end users and the manufacturers understand the concept and better comment on the validity of the product. This was the most essential phase of the practice-based research, as the idea was transferred between the researcher and the end users. The comments and feedback could then highly benefit the development of this screen. Acquiring the most realistic look of an interior and exterior screen setting is worth doing in the practice of interior design and architecture as the cost of printing the 3DPM and fixing it as a sample was beyond the funding of this research.

Figure 4-19: Exterior view of 3DP Mashrabiya screens in a possible Bahraini context. Source: Author rendered by DPI.

Figure 4-20: A realistic 3D rendering by 3dS Max by DPI to show the 3DPM screen and its shadowing pattern. Source: Author.

4.4.2 The validity of evidence-based research

Niedderer and Roworth-Stokes (2007) defined 'validity' as the concern for credibility in any research study, its results, and process. The choice of appropriate methods is linked to the quality of data gained from research. Practice- and evidence-based design and research should therefore be understood in relation to the research question investigated.

4.5 REFLECTIONS ON THE THEORETICAL AND PRACTICAL ELEMENTS OF THE UNDERTAKEN METHODS

Having gained an explicit understanding of this research problem following the literature review the researcher saw connections between methods and expected outcomes. The evidences and results of each method tested or implemented helped the researcher to comprehend the change on a social levels and further enhance the product on a functional and aesthetic level. New ideas and a better understanding of the research problem shaped the methods used. The 3DPM product is the result of the development of new design possibilities. With parametric, economic as well as 3DP manufacturing and material possibilities helping to generate new ideas and possible new forms.

Therefore, the process of adopting different methods to develop 3DPM can be considered as an 'accretive process' of practice informing theory and theory informing practice; (see Figure 4-21). The accretive process is 'the process of growth or increase by gradual additions' as defined by Investopedia (2016). While this process has been proven effective by Wallis and Grieg (2009). It should positively influence 3DPM as well. The methods used here may be reused by other product designers in the field of architecture or interiors. The variety of methods adopted in this research through different phases can link the practice of Mashrabiya making and end the engagement of end users and professionals in the research. The developing concept of a new SAFE 3DPM based on the skills of traditional craftsmen, and the input of manufacturers, architects and end users can help make the tacit explicit in terms of approaching design in the field of sustaining architectural heritage.

The analysis and discussion chapters (5 and 6) express more of the reflections and findings of the undertaken research methods. Both metaphor analysis and thematic analysis are used to generate a better understanding of the data collected from the different research tasks and phases.

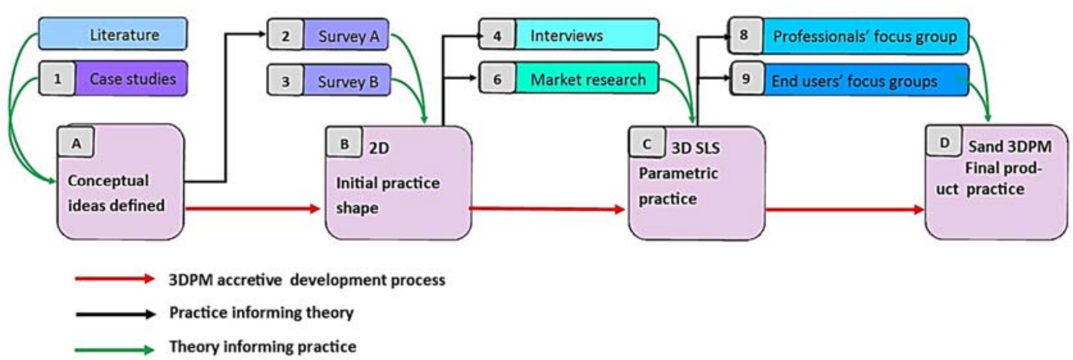


Figure 4-21 Accretive process of adopted methods in form 3DPM. Source: Author contribution.

4.6 CHAPTER CONCLUSION

This chapter provided a detailed description of the methods implemented in this research to triangulate its effectiveness. A hybrid mixed-method approach was adopted. Initial interviews were followed by case studies and a context-based survey, and then semi-structured interviews in a series of chronological tasks (see Figure 4-22). Nine tasks within three phases have been explained in this chapter. This has helped to develop a Mashrabiya model using 3D printing as a research practice. The model design form was enhanced through three stages and tested in terms of its SAFE values within professionals' and possible end users' focus groups.

The selection of methods and the chronological order in which they were implemented is based on the idea of design and innovation, where practice informs theory and theoretical information informs practice in an accretive process. The development of the 3DP Mashrabiya product practice is evidence of such an accretive process and is the result of the hybrid mixed-method research undertaken. Chapter 5 will present the findings from these proposed methods and their nine tasks. The aggregated data obtained from these methods will be run through three types of analysis: descriptive analysis, a metaphor analysis and a thematic analysis, as will be discussed in the next chapter.

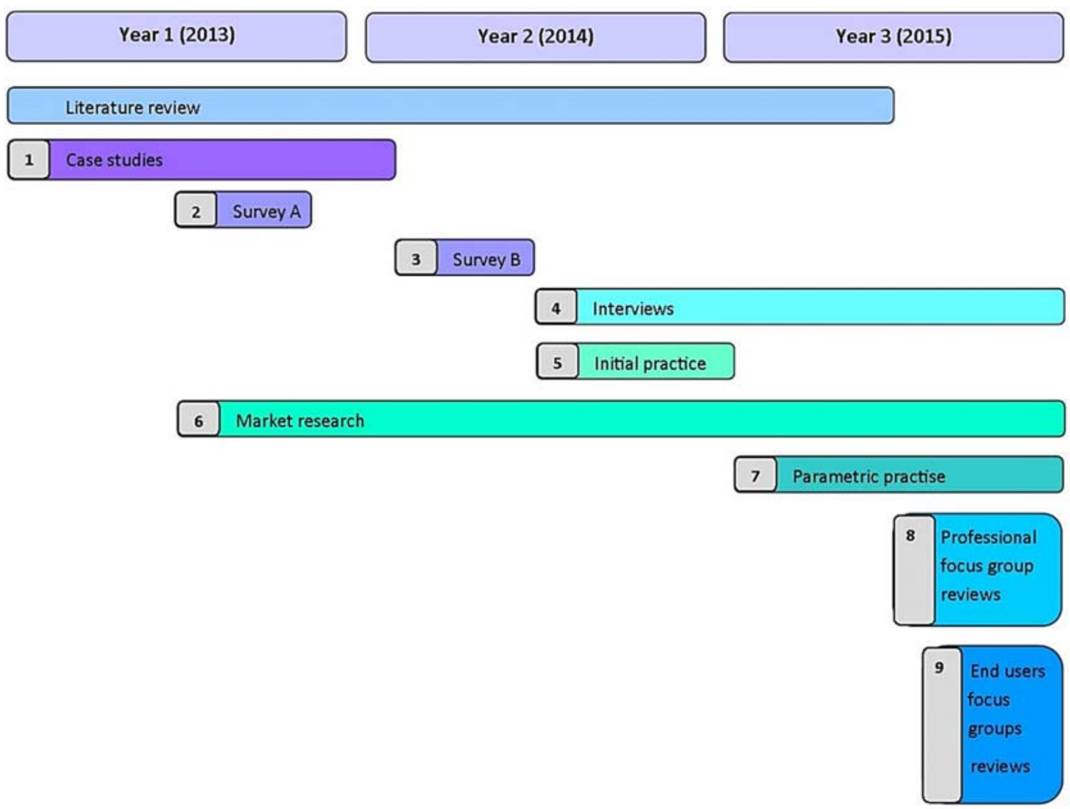


Figure 4-22 Research adopted methods map. Source: Author.

CHAPTER 5

"The overall aim of design research is to develop an accessible, robust body of knowledge that enhances our understanding of design processes, applications, methods and contexts. Often, this knowledge helps to define best practice and workable methods in dealing with design and design-related problems. It therefore has considerable potential for improving our use and management of design."

Cooper and Press (2007) cited in Collins (2010), p.21.

CHAPTER 5: RESEARCH DATA: FINDINGS AND ANALYSIS

5.1 INTRODUCTION TO DATA RESULTS

The aim of this chapter is to report the results obtained through the methodology that was explained in detail in Chapter 4. This chapter presents the findings gained from (1) the case studies, (2) the sample population survey, and (3) interviews and focus groups. Related secondary data are also presented here. The chapter focuses on the findings from the three phases of the research explained in Chapter 4, ranging between explorations of the theoretical data and practice-based contexts. Information is presented in figures, tables and charts. The data presented here is organised logically and cohesively within the SAFE framework (representing Social, Aesthetic, Functional and Economic values) formulated in Chapter 3; this is further discussed later in Chapter 6.

This research consists of three main phases; there are also about nine sub-steps. Each stage informs and guides the data produced in the next phase and influences the methods used, as explained earlier. The type of data from each of the phases is described and outlined in Figure 5-1, which describes the sequential and logical progression from one method to another. Data gained from each step are first presented individually; then, a thematic analysis reference to SAFE is used to analyse the data collectively. See Figure 5-2.

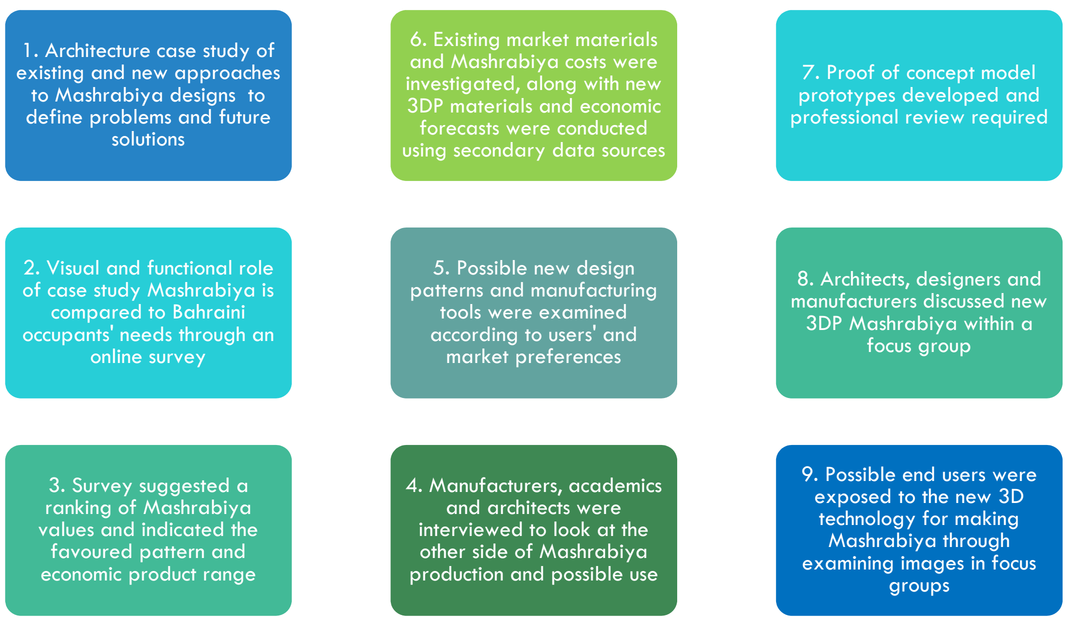


Figure 5-1: The sequential research data collection steps within the research's main stages. Source: Author.

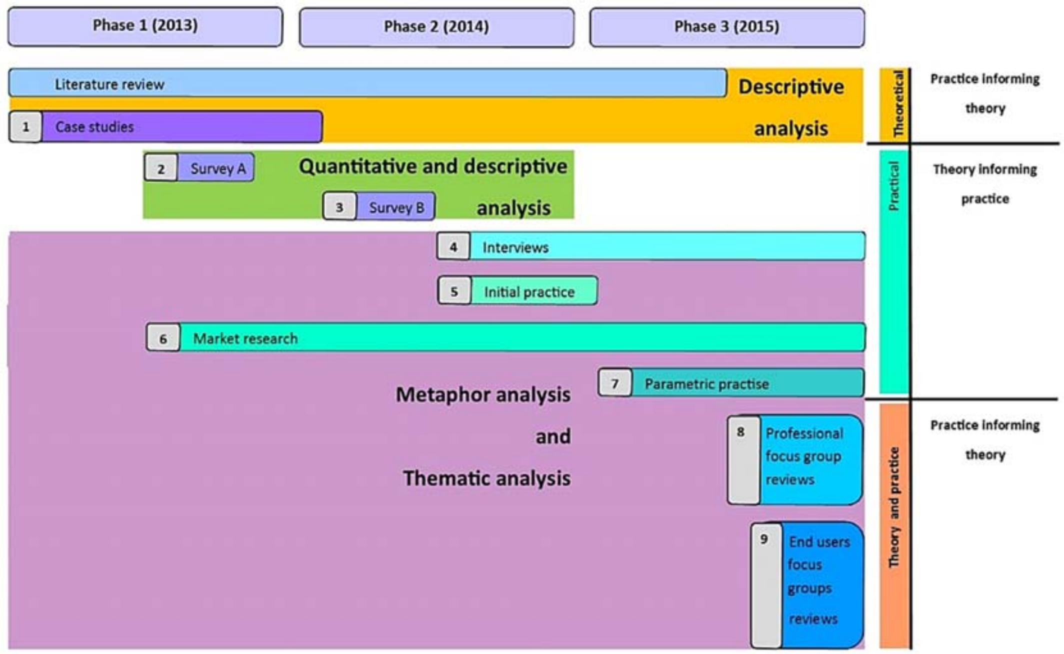


Figure 5-2: Research phases, tasks and related conducted analysis type. Source: Author.

Milton and Rodgers (2013) state that the majority of designers undertake qualitative rather than quantitative research. Categorisation is therefore an important task in analysing data and building up a full picture of the context. The need to look for themes and patterns, as well as relationships among the collected data, is a critical stage. This stage of any research aims at finding similarities and differences within the data that have been gathered. Furthermore, exceptions and contradictions may be found which will influence the findings.

Thematic analysis is considered by many researchers, such as Bryman (2012), as a common approach used in analysing qualitative data. The National Centre for Social Science in the UK developed an approach called Framework. Framework can be considered as a general strategy for assisting in thematic analysis. Moreover, Framework can be understood to be a “matrix based method for ordering and synthesising data” (Ritchie et al., 2003, cited in Bryman, 2012, p. 579). The following table, Table 5-1, represents a Framework approach sample in terms of the social theme analysis conducted.

A theme is considered to be a category defined by the researcher through the reading of the data. It relates to the research in focus, builds on codes and provides the researcher with a basis for a theoretical understanding of the collected data (Bryman, 2012). Thus, it can make a contribution to the specific research literature. An example can be seen in Table 5-1 below which represents a social theme analysis.

Table 5-1: Social themes within a Framework approach to thematic analysis. Source: Bryman (2012, p. 579).

Theme	Religion	Culture	Traditions	Personal choice
Interviewee 1				
Interviewee 2…				

Moreover, coding is therefore considered to be an important task where the researcher examines the collected data in order to best categorise information under certain themes. Bryman (2012) defines coding as a two-stage task. The first stage is to categorise unstructured material gained from open-ended questions in interviews while the second stage is to assign numbers to the created categories.The researcher relied on the effectiveness of the CAQDAS Nvivo 10 and SAFE values as node themes for the required coding categories.

The Nvivo coding process linking the relationship between the framework, theme and literature as secondary sources with primary data is exampled here. New nodes were created while the coding was in process in order to arrange new data within the new categories which will be later discussed in details. For example the economic value was taken from SAFE framework as a theme with a main node. Under the main economic node, sub-nodes were created while coding interviews and market data as well as focus groups responses. These sub-nodes included major sub-themes and factors that can influence the economic value of the 3D printed Mashrabiya. Such sub-nodes (sub-themes) included: Purchasing power, mind-sets, 3D printing market in Bahrain, Affordable screen price, customisation value, etc. By analysing the generated coding under each theme and sub-theme the researcher was capable of viewing the data and discussing its result on an integral and wider context as will be explained later in this chapter.

Validity was ensured at the data analysis stage using Cohen, Manion and Morrison's (2011) recommendations. Respondents' validation reduced 'the halo effect' where the researcher's prior knowledge of the data or the person(s) means that they carry certain judgements. Moreover, the use of appropriate statistical treatments and taking care to avoid subjectivity were other methods of ensuring validity. The following results are presented from each of the steps described above in a sequential format according to the year in which the results were collected.

5.1.1 Case studies (1)

The research relied on four different case studies. The reason behind selecting each of the case studies is described in Table 5-3. One local site case, Khalaf House, was compared to other two regional studies and one conceptual project using a new Mashrabiya design. The results and findings of each case study relied on the following primary and secondary data (see Table 5-2).

Table 5-2 Case studies information source. Source: Author.

	Case	Information source	Data findings / input year
	Khalaf House	Site visits: Abdulla Alkhan Photography archive and documentary leaflets from the Ministry of Culture, Bahrain.	Initial visit: August 2014; Second visit: February 2015
	Masdar City	Literature and scholarly articles, promotional media resources, such as blog diaries, YouTube visits and videos, architects' profile data.	2013–2014
	Albahar Tower	Interview with a main architect, literature about the Mashrabiya's kinetic performance.	2014
	Microclimates	Interview with architect Martin Postler from Postler and Ferguson.	May 2013

Table 5-3: Research's case study selection: Benefits and drawbacks. Source: Author.

Project name/ Case type	Uniqueness	Benefits	Difficulties
Khalaf House 1940s/ Manama, Bahrain Case study consisting of site visits	Original Bahraini Mashrabiya type	• Scale applicable to housing size. • Shares same research context in Bahrain. • Still existing and accessible. • Has original products of both Aggasi and Mashrabiya screens. • Built for a high-income family member. • High level of foreign workmanship incorporated.	• Not enough data in the literature about exact building information; mostly relied on word of mouth. • Mashrabiya construction cost not documented.
Masdar City 2009/ Abudahbi, UAE. Literature-based case study	Unique sustainable material	• Scale appropriate for development projects. • Provides a new application for material and pattern to produce Mashrabiya. • Design influenced by foreign culture and concept of origami. • Mashrabiya used within a sustainable context. • UAE context is similar to Bahrain.	• Could not obtain any feedback from users. • Functionality and cost not proven or documented in the literature.
Albahar Tower 2014/ Abudahbi, UAE. Literature-based case study	Use of parametrics and kinetics in new Mashrabiya design	• Scale appropriate for iconic buildings and landmarks. • Use of parametric design and building modelling to study Mashrabiya's possible behaviour. • Constructing new kinetic Mashrabiya that responds to weather conditions. • Modelling and manufacturing was the collaborative work of different specialists, both local and international.	• Building scale and budget do not match housing projects. • Pattern functionality and maintenance cost could be unreasonable in the long term.
Microclimates 2013/ Conceptual Literature-based case study	Use of 3DP possibilities	• Use of 3DP as a new and possible manufacturing technology. • Use of passive cooling system projected to ensure the product. • Mashrabiya concept using parametric algorithms to revive its pattern in a new design.	• Scale not applicable for 3D printing in a reliable way.

1. Khalaf House, Manama, Bahrain.

Haji Ahmad Khalaf Courtyard House is an existing example of a type of architecture developed in a thriving pearl industry. The owner, Haji Ahmad, was a famous pearl merchant and his house expressed his social class and love of excellent workmanship. Kazerooni (2002) states that the merchant himself was able to show his artistic tastes and ingenuity in various items in the house's architecture and its interior elements. He claims that Haji Khalaf's contribution to Bahrain and Gulf architecture was constructing his two houses with distinctive features. These included the use of fine pieces of carpentry that matched the woodworking standards seen in Iraq, Iran and Egypt.

It has been reported that the rich merchant employed a famous and fine carpenter from Baghdad. The carpenter, Hassan Baghdadi, produced the joinery and carpentry in this house, together with its Mashrabiya which were made like the ones seen in Iraq. The material used was the finest teak. The qualities of this type of wood include durability in harsh weather conditions and certain properties that do not allow insects and worms to damage it. Kazerooni (2002) reports that the owner's vision of this house went beyond the traditional architecture of Bahrain at that time. He wanted excellent craftsmanship that could be compared to the fairytale visions of the famous Haroon Alrashid in the *Thousand Nights* tale.

The Mashrabiya and Aggasi or Karkari were highly decorative in comparison to other items on the facade or in the house as a whole (see Figure 5-3). Baghdadi relied on a similar construction technique for the house's projected balconies with louvres tilting inwards, which can be seen in other traditional houses in Bahrain.

His construction allowed air currents to pass through the louvres while also providing privacy for the women of the family. The owner insisted on providing these women with the best view of the neighbouring activities and so the best decoration was used on these balconies. Small hinged windows which were richly decorated (see Figure 5-3) were also used by the women. The function and decoration of these windows was of great importance, as Kazerooni (2002) explains:

> *"As the females spent most of the time at the balcony, Mr. Khalaf wanted to provide his family the most luxurious space"* (p. 92).

The craftsman, Baghdadi, carried out all the craftsmanship and stencilling of the decorative timber in his wood workshop. Later, he would bring the wood to the site for nailing to the ceilings or fixing the panels to the balcony framework. Kazerooni (2002) also elaborates on the emotional and aesthetic quality of the Mashrabiya and louvres and the quality of light entering through them.

Figure 5-3: An archive photo of Khalaf House (main) in Manama, Bahrain. Source: Abdulla Alkhan photography archive.

Figure 5-4: An existing photo of Khalaf House which is still in use. Source: Author, 2014.

Figure 5-5: A closer view of the balcony woodwork. Source: Author, 2014.

2. Masdar City Mashrabiya

"Transforming oil wealth into renewable energy" and "the transition from a 20th-century, carbon-based economy into the 21st-century sustainable economy" resulted in great projects and initiatives like Masdar City, as claimed by Reiche (2010). Masdar City is located in the desert of Abu Dhabi in the United Arab Emirates and has been promoted as one of the worlds' first completely sustainable cities (Lau, 2012). The firm Foster and Partners, and the Abu Dhabi government, aimed to create a unique community that would use renewable energy and the latest energy-efficient building technologies and smart designs. Furthermore, Masdar City also provides a sustainability lesson in its master plan, together with the social implications of living sustainably. Masdar City seeks to provide a balanced sustainable solution by providing social equity, environmental awareness and affordable economic options.

Masdar City's overall objective focuses on enabling an advanced and high quality of life with the lowest environmental footprint. This aim is evident in the design of the Technology Institute building and its accommodation. The design concept relied on narrow streets and natural shading, which was achieved by raising the entire master plan on a 23-foot-high concrete base in order to maximise the city's exposure to wind. It also allowed the need for air conditioning to decrease (Lau, 2012). The design relied on several techniques of natural ventilation adopted from traditional regional architecture. The use of natural wind towers and roof day-shading can also be seen in the design. This was combined with highly developed mobility solutions and the adaptation of the 'One Planet Living' principles.

Masdar City's website claims that its Institute buildings and campus will be able to consume less energy and water by using clean technology. Statistics taken from the Masdar City website demonstrate their claim that the campus will use about 75% less cooling energy, about 95% less energy to provide domestic hot water, and 70% less energy to provide potable water. Moreover, 70% less electricity is expected to be consumed owing to their reliance on a combination of passive and intelligent design solutions.

One example of the passive cooling techniques used is the modern Mashrabiya-like screens, which can be seen in **Error! Reference source not found.** and Figure 5-7. The modular GRC screens designed by Jean Marc Castera provide a way of controlling privacy but also offer an aesthetic treatment to the facade. The aim behind developing these screens, according to Palmer (2011, p. 3), was to create a "self-shading façade". The building's facade responds positively to the orientation. Moreover, it provides shade for adjacent buildings by the amount it covers the area below. Using a unique shading curve from an oblique view provides the pleasure of being able to overlook the public street below without being looked at.

Figure 5-7 Masdar City facades with GRC Mashrabiya screens. Source: Masdarcitu.ae (2015).

Figure 5-6 The GRC Mashrabiya modular unit imported to site. Source: Palmer (2011, p. 12).

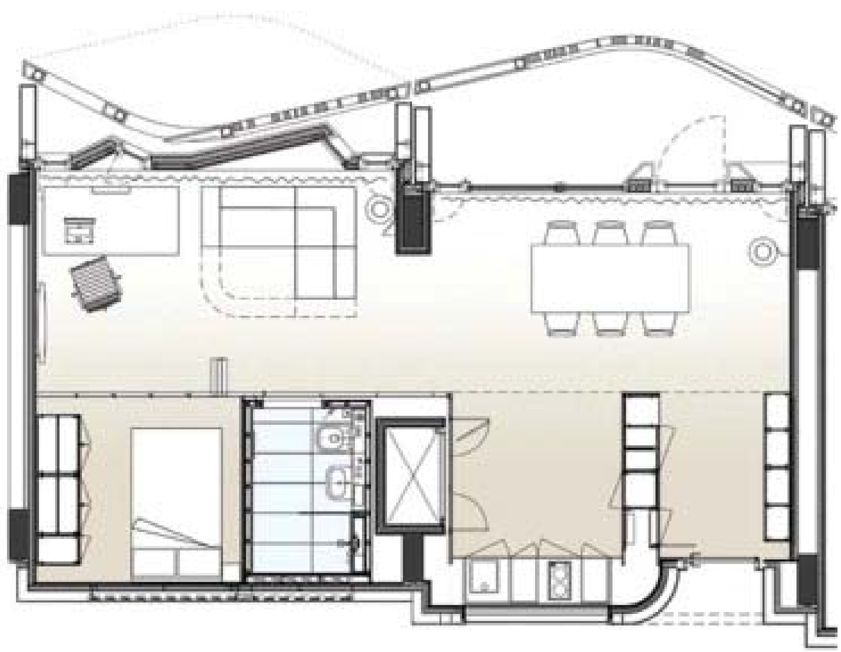


Figure 5-8 Masdar Institute apartment with Mashrabiya. Source: Abdelsalam and Rihan (2013, p. 165)

The design of the facade relied on a triple skin technique, the outer Mashrabiya layer being used for aesthetics and privacy, and the inner glass layer being a combination of timber-framed windows and aluminium glazed panels with a door opening into a small covered balcony, as seen in Figure 5-8. An average ratio of 35% glass to solid area was used in order to minimise heat gain, with variations of this ratio being used according to the floor and the screen levels. A ratio range of 25% to 45% glass to solid area differed

between floors, according to Palmer (2011). Even the inner aluminium is a layer of 90% recycled aluminium that can reflect light within the balcony.
Thermal and glazing calculations were studied using the Ecotech program to ensure heat gain was reduced as much as possible. The third layer used a high insulation material wall to absorb any heat escaping from the first and second layers of the facade. By controlling the facade's parameters, Foster and Partners succeeded in reducing the conditioned air that was lost through the facade. Setting a unique U-value of about 1.1 W/m2k for glazing and 0.25 W/m2k for all solid walls resulted in the technique of 'self-veiling', which is very powerful in terms of sustaining energy while maintaining the concept of the heritage-inherited Mashrabiya screen.

Abdelsalam and Rihan (2013, p. 165) discuss the design trend used by Masdar City Mashrabiya, which they note followed a "*new contemporary interpretation trend*". They define this trend as an attempt to express the vernacular traditional approach in a contemporary way. Foster and Partners' success in understanding the heritage values and role of the Mashrabiya was further enhanced by their approach in designing a modern curved GRC Mashrabiya block instead of a lathe-turned wooden one. The following are the benefits gained from this design approach, as outlined by Palmer (2011):

1. The role of the Mashrabiya as a first layer in the three layers of the facade helps to reduce heat gain and allow self-shading at the same time.
2. The curved Mashrabiya form provides an oblique view and hence caters for the control of privacy using modern patterns.
3. Using GRC modular screen types and materials allows off-site manufacturing of ready-made balcony blocks and Mashrabiya screens, which can then be transported to the site.
4. The relation between the size and density of the Mashrabiya screen's geometry is directly linked to the building's orientation.
5. The screen relies on the technique of having a deep opening to reduce heat gain while creating dramatic lighting effects. This also means that the benefits of daylight can be maximised by allowing bounced light to enter the City apartments.

"Thinking global, acting local" is how Palmer (2011, p. 4) and Abdulsalam and Raihan (2013) endorse Masdar City as a blueprint for a sustainable 21st-century city. Lau (2012) also sees the Masdar initiative as a successful model of an 'eco-city', one that can truly endorse sustainable urbanism. This innovation in urban planning and capitalising on the city's environmental advantages benefits from aspects of traditional architecture in a way that employs an expensive technological solution to serve a vision of the future. Not only does Masdar City promote sustainability but it can also be considered as an example of a project that utilises the financial potentials of new technologies to combat social concerns (Lau, 2012). In response, modern societies, with their economic prosperity, can retain sustainability while moving forward.

To conclude, Masdar GRC Mashrabiya screens are therefore an example of a sustainable and social solution for an eco-city that reworks modern technology as an economical solution to facade design.

3. **Albahar Tower**

The Abu Dhabi Investment Council launched an international competition to design its headquarters in 2007. Aedas responded to the client's needs by building two 25-storey buildings. The design required contemporary architecture that would reflect the region's architectural heritage with the use of modern technology (Oborn and Chipchase, 2012). The design also responded to Abu Dhabi's new 2030 vision that promoted a framework of environmental responsibility and awareness of sustainability.

Aedas relied on the sources and designs of Islamic architecture and vernacular traditional settlements in an inspirational concept that was able to satisfy the harsh desert climate of the region. The company therefore first considered diagrams of the sun's path and pointed outwards those facades that received most of the solar gain. Therefore, the resulting design solution claimed to be derived from Islamic architecture and its geometric patterns, together with influences from nature and sustainable technology.

The Mashrabiya screen was taken as a source of inspiration due to its role in providing visual privacy, and in reducing solar gain and glare. The reinterpretation of a Mashrabiya was a challenge in terms of changing it from a fixed double skin treatment to a more dynamic one. By looking at the disadvantages of curtain walls and field shading devices, Oborn and Chipchase (2012) explain the merits and disadvantages of the possibilities in hand. Examples of these are presented in Table 5-4 below:

Table 5-4: Merits and disadvantages of shading types based on Oborn and Chipchase (2012).

Fixed Shading	Curtain Walling	Dynamic Shading
- Has a limited geometry. **- Cannot be optimised for all conditions**	-Relies on heavily tinted glass to comply with GCC needs. -Resulting interiors require more natural daylight. -Requires more lighting in the interior.	- Has a flexible geometry - Results in using less tinted glass

	-Excessive use of internal blinds.	

The innovative new and dynamic Mashrabiya was proposed and brought to fruition by the architect Abdulmajid Karanouh. The new form was designed to expand like an umbrella in a form of origami. This concept was more appealing when the structural consultant, Arup, agreed that such a form could reduce the cooling load by about 20%. The dynamic Mashrabiya was simulated first to react to the sun's movement throughout the year. The geometry decreases to none on the northern side of the building where it receives minimum daylight. A pre-set program was used to control the kinetics of the Mashrabiya skin and make it respond to daylight and the sun's movement with data being entered daily and yearly.

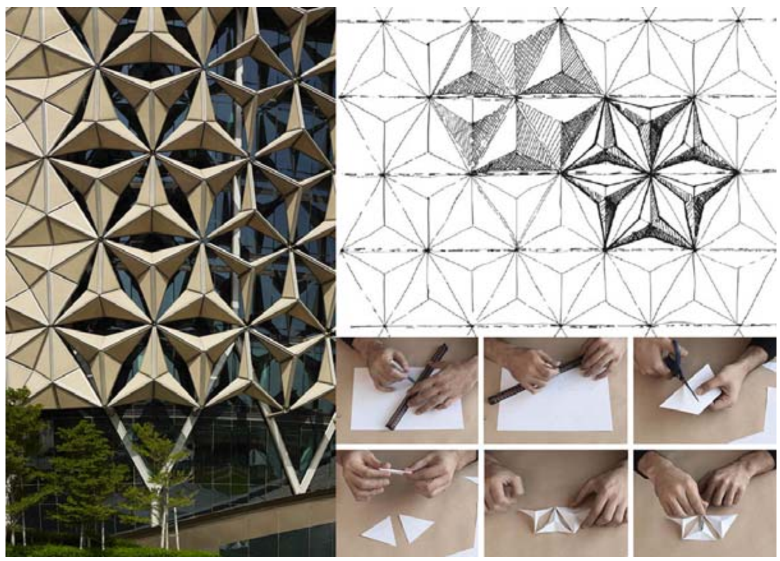


Figure 5-9: Albahar Tower's dynamic Mashrabiya concept by Abdulmajid Karanouh. Source: http://www.ahr-global.com/Al-Bahr-Towers

Through personal communication and an interview with the architect, Abdulmajid Karanouh, in April 2013, he explained the concept behind the Albahar Tower's Mashrabiya design and pattern. He noted that the ideology behind the pattern was derived from the basic Islamic idea of 'tawheed' or unification. This is reflected and symbolised by the circular, spherical and orbital motion of everything in the universe.

Karanouh noted that the geometry, like all Islamic geometries, is composed and constructed of a series of linked interrelated and intersecting circles and spheres whereby the intersecting nodes are linked by straight lines and filled with triangular surfaces based on performance and functional criteria. He claimed that the concept is universal (as Islam is a universal faith and not limited to certain people at certain times). As a Muslim architect, Karanouh believes that this Islamic concept brings much depth and richness, as can be seen in all Islamic art and architecture where the styles, colours and materials used vary significantly across the Islamic world and are not limited to an imperialist, imposing style such as that of the Romans or the Greeks.

He concluded by noting, based on the above, that the geometric composition generated for Albahar Towers was an attempt to fuse the cultural requirements of the Middle East and the West in a universal manner; it was not only limited to the Emirati culture. He justifies this by acknowledging that many people from all over the Middle East, as well as many Westerners, will occupy the Towers or be involved in its design (see Figure 5-9).

The real Mashrabiya units were composed of about 30 elements and placed almost 2 metres in front of the glass facade; they were framed with aluminium and stainless steel to resist corrosion. This is claimed to allow shading of about 80% while still admitting a beneficial amount of daylight. Actuators and shear forces were carefully engineered and calculated, along with the selection of special material to cater for the harsh climate in Abu Dhabi. Each element was assembled and tested in China before being disassembled and shipped to Abu Dhabi where they were individually reassembled, tested and then fixed onto the facade. See Figure 5-10.

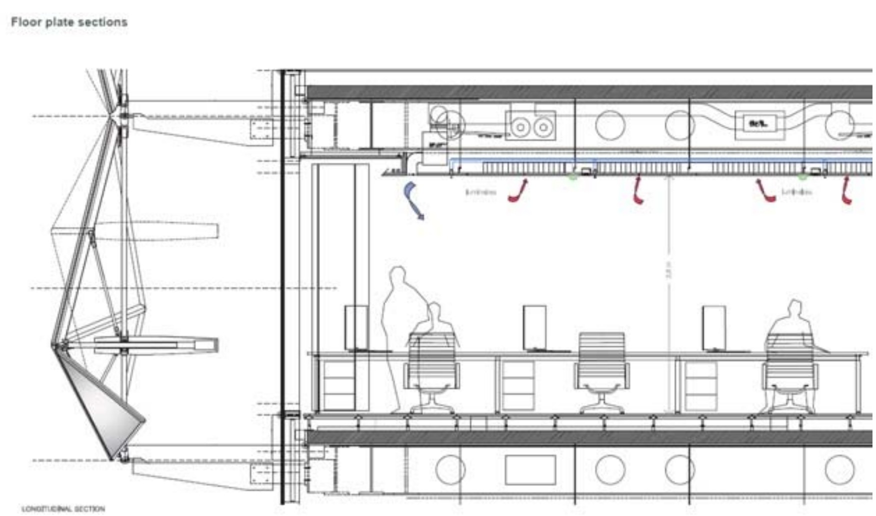


Figure 5-10: A floor section within Albahar Towers. Source: https://duranvirginia.files.wordpress.com/2013/04/virginia-duran-blog-unusual-facades-al-bahar-towers-origami-architecture-section.jpg

A full size mock-up and a Mashrabiya prototype were built by the sub-contractors in China to study how the Mashrabiya and actuators would function in actual conditions. They were also exposed to durability testing to estimate the behaviour of the proposed Mashrabiya over 75 years of life (Karanouh, 2013). Another U-value test was carried out to confirm the selection of the PTF fabric of the Mashrabiya. The final manufacturing processes of mould making, casting, machining, finishing and turning resulted in the approved Mashrabiya (Oborn and Chipchase, 2012).

Karanouh (2009, 2013) explained how the design's parametric algorithms and site data were digested, communicated and channelled down to the wider supply chain and the actual labourers who built it. BIM, computation and parametric algorithms, in his opinion, introduced a fourth dimension to the design that is worth investigating.

Oborn highlights in this context how often designers become disconnected from the manufacturers and how important it is that they should not allow this to happen. The ease with which a beautiful concept can be designed on a computer can sometimes overshadow the fact that someone actually then needs to make it. A case that integrates all these factors is presented next.

4. Microclimates

The Microclimates project proposal, designed by the UK-based company, Postler and Ferguson, can be considered a new approach in the revival of the Mashrabiya concept. The designers were inspired by traditional Islamic architecture and its lessons in sustainability were manifested in the use of the vernacular Mashrabiya and earthen walls (Postlerferguson, 2013). The passive cooling characteristics of the Mashrabiya and its ability to control light and airflow inspired them to create the Microclimates. See Figures 5-11 and 5-12.

The design was produced using custom-built software and a three-dimensional interpretation of Mashrabiya. The idea was to build the form from local clay and to structure the complex form with a large internal surface area. The designers also intended to use the form to cool public spaces by relying on passive cooling to condition the surroundings efficiently.

By proposing several 1 to 2 and 3-metre-high towers or pods made out of 3DP sand, Postler and Ferguson did not just challenge current Mashrabiya manufacturing but also challenged 3D printing technology in terms of building such a large-scale architectural form. The technology developed by D-shape seemed capable of producing such an element.

Figure 5-11: Microclimate's 3DP pods. Source: Postler and Ferguson, 2013.

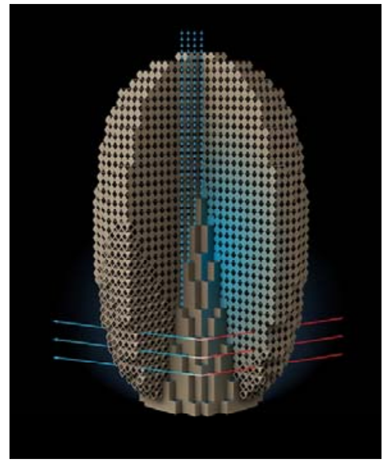


Figure 5-12: Mashrabiya concept of evaporative cooling within the pods.

Postler and Ferguson (2013) claim that the Microclimates should not be considered to be just architectural installations. The use of advanced computer-aided manufacturing technology makes it a building language that, it is proposed, can be reused several times in the future.

An online interview with Martin Postler, which was conducted in May 2013, explains more about the idea and the generation of the pattern. He first explained that Postler and Ferguson were invited to submit a design concept to an organisation called "Traffic", based in Dubai, UAE. The aim was to design a form that would reflect the local architectural tradition. The Microclimates models were prototyped and displayed in the Traffic Gallery. Although the sand material was never really tested due to the need for greater financial backing, Postler asserted that the general idea of printing a porous material out of sand in order to evaporate water to cool a space was possible. He described the process as "doable and scientifically promising"..

The form was generated using the Rhino program and an algorithm that was developed by Postler and Ferguson. The design approach considered the Mashrabiya as a system with a simple geometric pattern. The next step was to make that pattern a very complex one using additions and also by rotating the same pattern in a repetitive format. The designer developed simple three-dimensional volumes that they described as a diamond-shaped cube which looked like a voxel. The form could then be more closed or opened up, depending on where the design or the pod form morphed into a solid or a transparent one. The designers then arranged the cubes and shaped the pods using special software.

The evaporative cooling effect was calculated, as Postler explains, through the open/closed ratio of the pod structure. Without relying on a tested formula, but by common design sense, they knew that the more open the objects were, the more the evaporative cooling would increase by increasing the surface area exposed to the air.

The design of the Microclimates offers endless design possibilities. They could be integrated into public spaces, such as bus stops or indoor wall partitions, or even window frames. They could, as Postler hoped, be further developed by working with bigger organisations and scientific research groups that could actually build and test the proposed 3DP structure. 3DP technology was chosen in this case as Postler thought of it as the only possible way to produce such kinds of structure. He anticipates a bright future for this technology in both an architectural and a cultural sense once the innovative production of 3DP is combined with positive and sustainable design thinking. D-shape, led by Enrico Dini, would have been nominated to construct the pods.

The delivery of such unique design concepts, as Postler explains, could be a collaborative project between their design group, who would deliver convincing arguments using the language of architecture, and scientific groups and manufacturers. The original idea was not simply to build Microclimates in hot regions like Dubai and the Middle East. Postler outlined their novel idea in the comparisons between technology and cost which follow. He concluded that the actual cost of the pods would depend on the time taken to 3D print them while the material and operating costs might be next to nothing, as can be seen in Table 5-5:

Table 5-5: Microclimates: Cost comparison. Surce: Postler (2013).

Microclimates Proposal	Cost
Transportable large 3DP machine to be shipped to site, set up and run	Depends on area location and printing time
Use local sand	Should be free or very cheap
Minimise energy used by relying on solar panels	Should be cheap

5. **Excluded case studies**

Although architect Hassan Fathy (1900–1989) can be counted as the first to propose a new Mashrabiya in modern architecture, as documented in the literature, his project, the 'new Gourna', was not included in this research although a number of scholars in the literature (e.g. Hui, 2005; Miles, 2006; Elshorabji, 2010; Ibrahim, 2012) have included his work. It is excluded here, however, because the type of Mashrabiya and the weather conditions, as well as the social attributes, were not similar to those of countries in the Gulf region, such as Bahrain. His noble thoughts about creating architecture that uses suitable local material and that is permanent and expresses real community needs, values and culture is evident in his designs. His lessons on constructing both socially and environmentally responsible elements and designs have been widely studied and they are acknowledged in this research but are not repeated here.

Announced in April 2015, another potential case study could be the new 2,000 square metre office building which is to be built in Dubai using 3DP technology. This building is part of the Dubai 'Museum of the Future'. The focus of this project is to nominate Dubai and the Emirates as a centre of design, technology and architecture. See Figure 5-13. This case study project was excluded as it is a very new one and not enough information was found in the literature about it.

Figure 5-13: The 3DP office building of the Museum of the Future in Dubai. Source: https://www.3dprintersonlinestore.com/dubai-gets-future-ready-with-3d-printed-office-building

5.1.2 Survey results (2)

Surveys were conducted in two stages and for two different aims. The first survey (A) investigated the awareness of 3D printing as a new technology in Bahrain during the first workshop conducted in the Alrewaq gallery in August 2013. This initial survey provided an understanding of the market and the target audience of the technology in Bahrain. The second survey (B) targeted the Bahraini population, as described in Chapter 4. It was distributed online to understand SAFE value ratings by various respondents in Bahrain from different social levels. Both survey results helped in setting the future forecasts for the technology and its users and future innovators, as analysed in the following sections.

A. 3D printing market survey, August 2013

This survey was distributed as a first step towards understanding Bahrain's 3D printing market and its potential growth rate. The survey targeted 30 persons who participated in a workshop about 3D printing in August 2013. It was distributed after the 3D-printing workshop, which was the first of its kind and was sponsored by the American embassy art space in Adlya, Bahrain. The survey was also distributed online to reach other Bahraini residents.

The majority of the respondents were in the 21–29 age range and they were all from a community group interested in this advanced technology. Respondents came from various disciplines although the greatest percentage (43%) came from art and design backgrounds, or from architecture and engineering, which accounted for 37% of the total number of respondents. See Figure 5-14 and Figure 5-15.

Bahrain's manufacturing market is developing quickly because of the governmental and industrial support it attracts. However, the fact that the first 3D printing and consultancy shop opened its services to the public on April 2013 can be said to be one of the reasons for the late introduction of 3DP to the Bahraini market, as noted

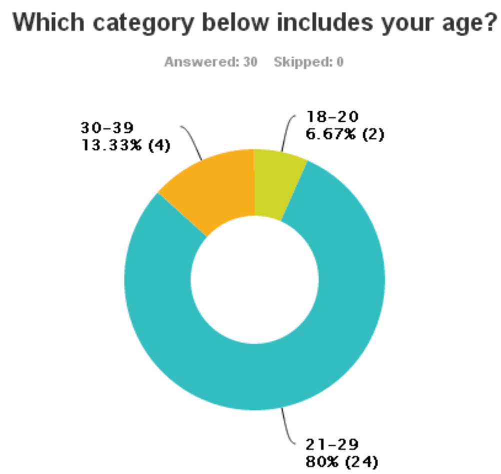


Figure 5-14: Age categories of participants of first 3DP workshop in Bahrain. Source: Author.

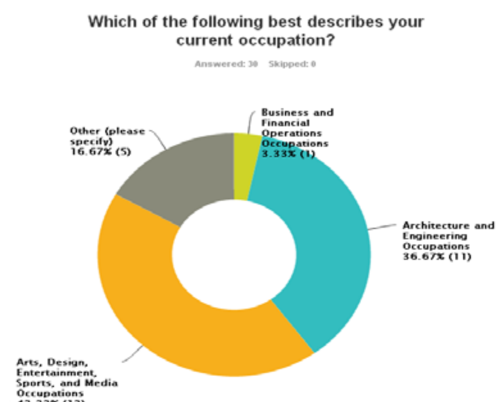


Figure 5-15: Participants' occupations

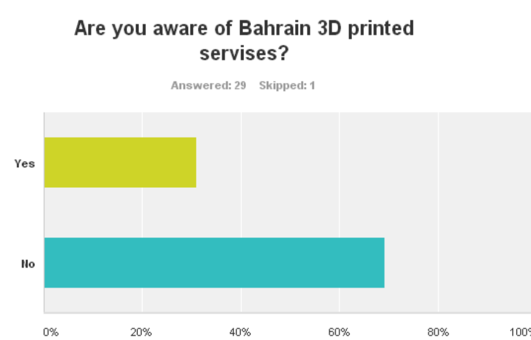


Figure 5-16: Level of acquaintance with 3DP. Source: Author.

by Khalid Engineer in 2013, owner of KBProto, (Personal communication). As a result, it might be thought acceptable to find that 80% of the respondents were completely new users to 3D printing.

The next question was asked to understand the contexts in which the respondents would be attracted to use 3D printing. The majority answered that they wanted to use 3D printers to produce design models or artistic sculptures. A few, around 3.33%, were interested in using it for domestic functions. Although this might seem a disappointingly low percentage, it is understandable, since all users are new to this technology and its possibiities. See Figure 5-17.

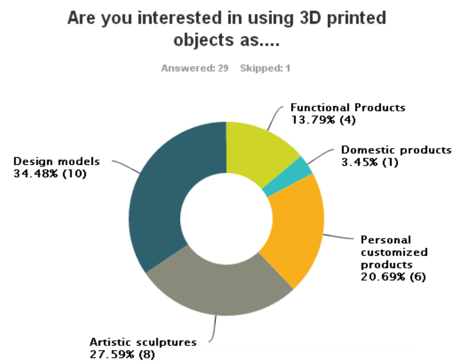


Figure 5-17: Possible 3DP objects. Source: Author.

The next question, presented in Figure 5-18, aimed to obtain an understanding of the possible types of services in the 3DP market and their availability. Very few of the respondents knew about the 3D-printing services in Bahrain. Only two respondents were aware of an actual 3DP service.

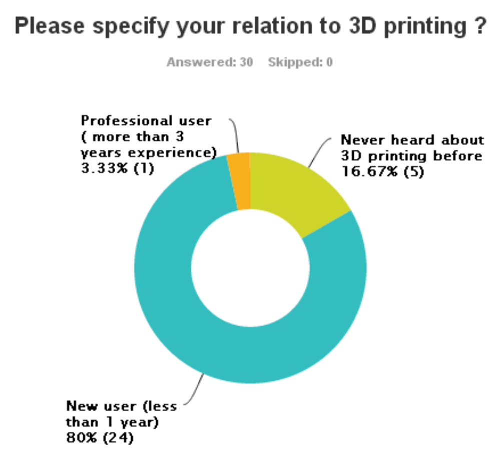
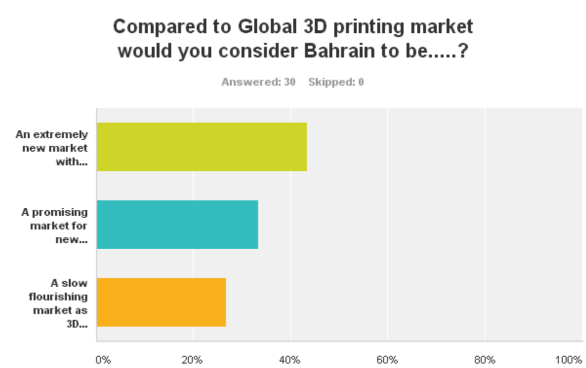


Figure 5-18: Popularity of 3DP in Bahrain. Source: Author.

Around 70% of the respondents agreed that they had never heard of 3D printing before in Bahrain. See Figure 5-18. In fact, the majority of respondents, 43.3%, perceived the Bahraini market for this type of technology as being fairly new.

However, the last question showed that almost all respondents were optimistic about this technology and planned to use it in the near future as 33.3% of the respondents perceived it as a promising market with the potential to grow more in the following years. However, 26.67% considered it as a slowly flourishing market. See Figure 5-19. A sample copy of the distributed questions is attached in the Appendix D.



Answer Choices	Responses	
An extremely new market with beginner approach to 3D printing	43.33%	13
A promising market for new invention and 3D creation	33.33%	10
A slow flourishing market as 3D printed objects are still too expensive in Bahrain	26.67%	8
Total Respondents: 30		

Figure 5-19 Bahrain's 3DP market compared to Global market development. Source: Author.

B. SAFE values of window screens in Bahrain

While the first survey targeted the knowledge of 3D printing and its market users in Bahrain, the second survey was distributed to members of the general population of Bahrain during May 2014. This was essential to cover both the possible manufacturing market and its potential users. The second survey, which targeted both Bahraini and non-Bahraini residents, aimed to explore their opinions about the following:

1. The types and sizes of housing, as well as ownership categories
2. Factors behind choosing an appropriate shading device
3. Their preference for the type of shading device within their own property
4. The preferred type of pattern for a shading device design
5. The value of customised and personalised window designs in relation to primary construction values
6. Average price of a shading device.

The general demographics of the respondents who took the online survey were diverse, covering most areas of the Bahraini population. The survey gained 193 responses from both Bahraini nationals and Bahraini residents (91% Bahraini and 9% non-Bahraini). Around 122 female respondents participated in this survey, as well as 69 males, with a ratio of men to women equalling almost 1:2. The majority of the respondents (186) were Muslims (96%) and 7 respondents (4%) were non-Muslims. The Cronbach Alpha (α) for the whole sample size was calculated to be 0.78. A range of between 0.7–1.0 indicates that an acceptable level of reliability has been achieved. Therefore, it can be said that this survey has research reliability.

The analysis of the survey results relied on a descriptive method used to examine and quantify the qualitative data that had been gathered. The respndants age group targeted Bahraini and nonBahraini over 18 years from different social levels of the Bahraini society. Figure 5-20 represents the age groups of the survey respondents, with the majority (44%) being aged between 25–35 years old while respondents under 25 years of age accounted for 26% of the total number of respondents. The middle age groups (i.e. 36–45 and 46–55 years old) accounted for 17% and 10%, respectively, of the total number of respondents while the lowest response was from the older group who were aged between 56 and 65 with a 3% response

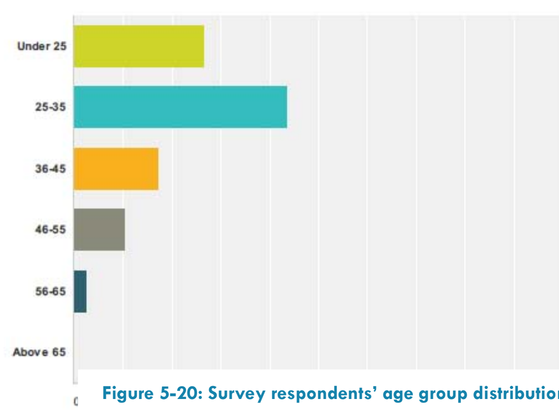
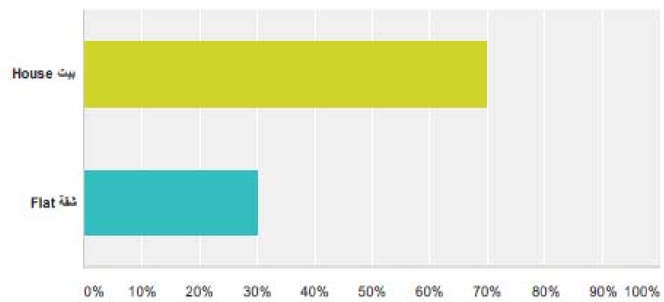


Figure 5-20: Survey respondents' age group distribution.
Source: Author.

rate. This is understandable as the older members of Bahraini society groups are generally not interested in taking online surveys.

The majority of the respondents (132; 70%) were house owners or were living in a house when they responded to the survey, as can be seen in Figure 5-22. The other 56 respondents (30%) were owning or renting flats. Furthermore, the property types of the respondents were of several types. The most common (119; 62%) were privately owned properties, as represented in Figure 5-22, while 29 respondents, or 15% of the sample, were living in rented property. 26 respondents (13.5%) were living in social housing accommodation offered by the Bahraini government to locals for affordable, long-term payments. 12 respondents lived in a shared property; this included living with parents or in-laws. The minority (3.6% or 7 respondents) were planning or constructing a new property at the time of the survey.



Answer Choices	Responses	
House بيت	69.84%	132
Flat شقة	30.16%	57
Total		189

Figure 5-21: Respondents' property type. Source: Author.

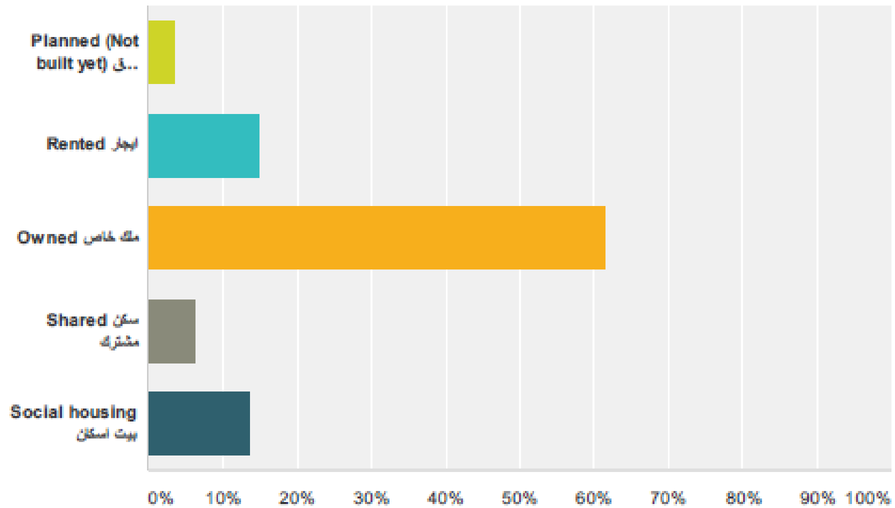
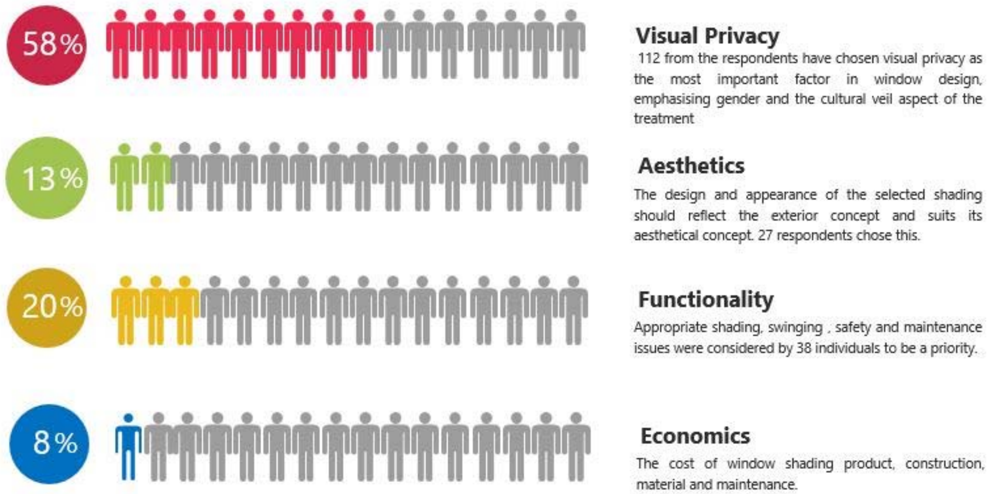


Figure 5-22: Respondents' property type. Source: Author.

The ranking of the function of window shading devices varied among respondents. See Figure 5-23. Nevertheless, visual privacy was chosen by the majority (122 respondents; 58%) as the most important issue that determined their selection of window shading. A relatively similar percentage (14% and 15%) of respondents chose aesthetic and functional performance, respectively, as the most important factor in determining the selection of shading. The cost and construction material of the shading device, as well as the maintenance cost, was considered to be the first priortiy of only 16 respondents (8%) while environmental efficiency and material sustainabiity was graded as being least important by 10 respondents (5%).

When asked about further factors that could influence the selection of a shading device, 166 respondents did not suggest any other factors. On the other hand, 4 respondents did not answer this question and 23 respondents, about 12%, agreed that there might be further factors that could influence their decision-making. Examples of their suggestions are outlined here:

- Consideration of the amount of sunlight entering the space through the shading device and how the shading responds to the building's orientation.
- Consideration of the reflection of the sun's heat to prevent it from penetrating the interior of the house.
- The colour of the shading device, its frame and glass, if it had any.
- The ability of the device to be reused in the house design and redesign process.
- Relationship of the device to the culture and heritage of the country in context.
- Consideration of the manufacturing country and the type and quality of the product.
- Consideration of the device's safety.



	1	2	3	4	5	Total	Average Ranking
Visual privacy: Window treatment should respect gender and cultural veil not to show the interior of the room during day or night to outsiders. الخصوصية والستر لاحترام حرمة المنزل ليلا و نهارا	**58.03%** 112	**17.10%** 33	**12.95%** 25	**8.29%** 16	**3.63%** 7	193	4.18
Aesthetic: The design and appearance of the selected piece within the exterior image. الخواص الجمالية والشكل الخارجي المناسب للشكل الهندسي للمنزل	**13.99%** 27	**26.42%** 51	**22.28%** 43	**20.21%** 39	**17.10%** 33	193	3.00
Function: appropriate shading, swinging, safety and maintenance. الخواص الوظيفية كالامان والتظليل والصيانة	**14.51%** 28	**28.50%** 55	**29.53%** 57	**18.13%** 35	**9.33%** 18	193	3.21
Environmental efficiency: Material used sustainability, passive cooling and thermal heat transfer. الخواص البيئية كالمواد المستخدمة و القدرة على التهوية	**5.18%** 10	**15.03%** 29	**20.73%** 40	**31.61%** 61	**27.46%** 53	193	2.39
Economics: The cost of the product, its construction material and maintenance cost. الخواص الاقتصادية كسعر المنتج و تكلفة التركيب و الصيانة الدورية	**8.29%** 16	**12.95%** 25	**14.51%** 28	**21.76%** 42	**42.49%** 82	193	2.23

Figure 5-23 Ranking of SAFE drivers by respondents in selecting a window shading device. Source: Author.

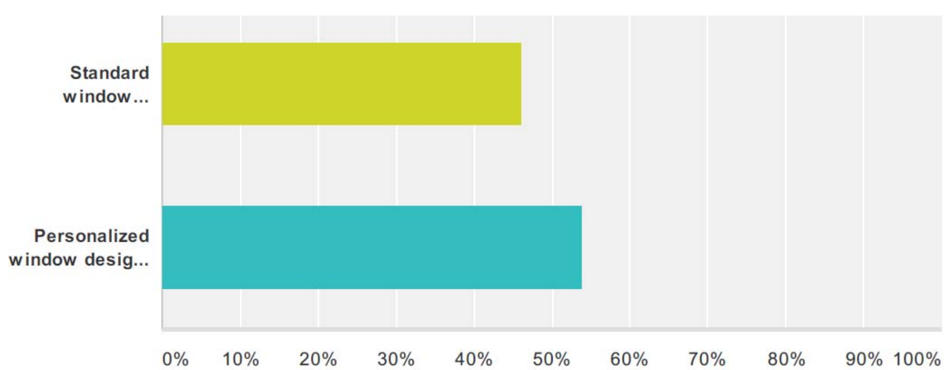
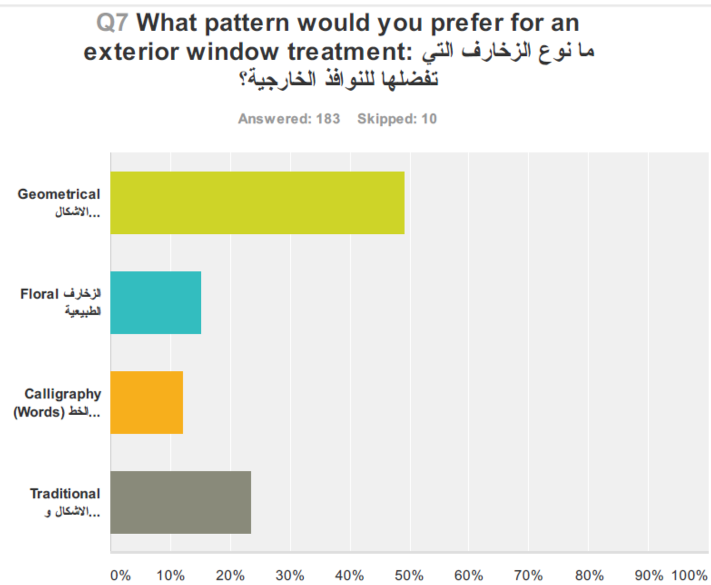


Figure 5-24 Window type preferences. Source: Author.

The selection of a preferred shading device varied slightly between standard window shading and personalised types. See Figure 5-24. The majority of respondents (104; 54%) preferred selecting a personalised window design that could include wooden louvres or Mashrabiya, etc. The other 89 respondents (46%) chose a standard window with a simple alluminium frame and the reflective double glazing commonly used in Bahraini dwellings.

The preferred type of pattern for a shading device design ranged between the following four types of Islamic ornamentation (see Figure 5-25): geometric patterns, floral, calligraphy, and traditional shapes and patterns. Most of the respondents (90; 49%) selected the geometric patterns as their preferred type while the other half of the respondents divided their selection between traditional, floral and calligraphy patterns. 43 respondents (24%) liked traditional patterns, 28 (15%) preferred floral patterns and 22 (12%) chose patterns of calligraphy. Unfortunately, 10 respondents failed to answer this question.



Answer Choices	Responses	
Geometrical الاشكال الهندسية	49.18%	90
Floral الزخارف الطبيعية	15.30%	28
Calligraphy (Words) الخط العربي	12.02%	22
Traditional الاشكال و النقوش التقليدية	23.50%	43
Total		183

Figure 5-25: Preferences for shading device pattern types. Source: Author.

When asked about the value of customised and personalised window designs compared with primary construction values, the respondents were divided almost equally. A slightly larger number of respondents, 97 (51%), considered personalised shading as an essential value compared to building cost. However, 95 respondents (49%) considered the design of personalised and customised windows as bringing added value to the building and construction cost. See Figure 5-26.

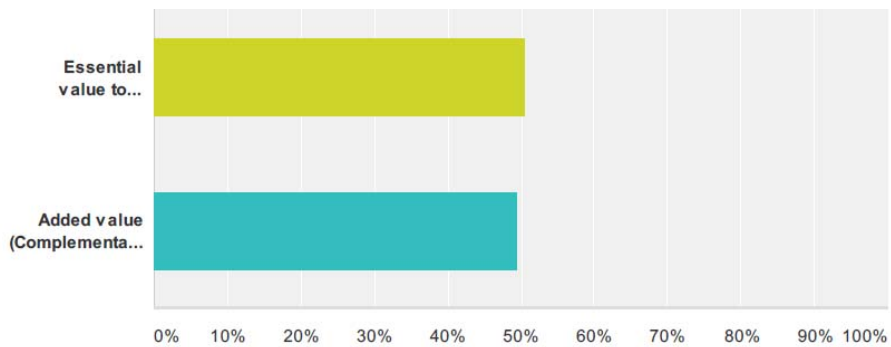
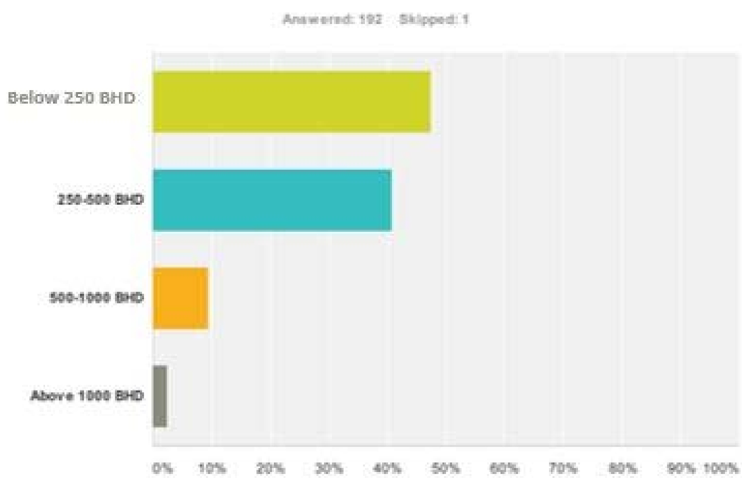


Figure 5-26: The value of personalised window shading devices to building cost. Source: Author.



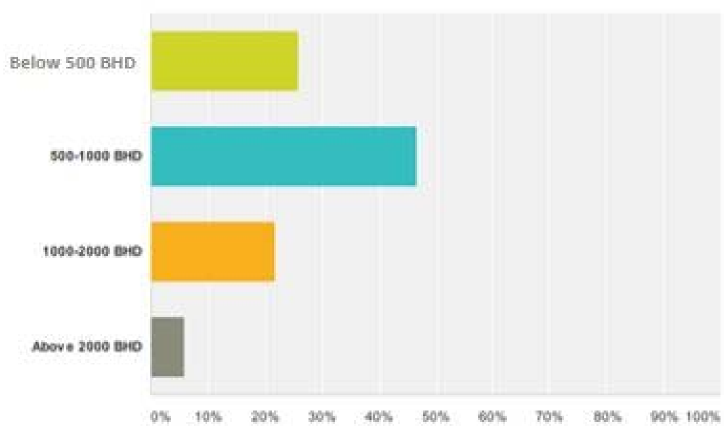
Answer Choices	Responses	
Below 250 BHD	47.40%	91
250-500 BHD	40.63%	78
500-1000 BHD	9.38%	18
Above 1000 BHD	2.60%	5
Total		192

Figure 5-27: The affordable cost range of a personalised window treatment. Source: Author.

The average price of a shading device that Bahraini residents could afford ranged between expensive and affordable. See Figure 5-27. The majority of respondents chose to pay a price that ranged between 250–500 BHD or below 250 BHD (£438) for a personalised window screen. 91 respondents, about 47%, decided that a personalised window screen should cost below 250 BHD, while 78 respondents (41%) were williing to pay in the range of 250–500 BHD (£438–£875) to own a personalised screen. However, only 18 (9%) respondents said they would pay 500–1000 BHD (£875–£1750) for such a screen while only 5 respondents (3%) would pay above 1000 BHD (£1750) to buy this type of screen.

The survey targeted various classes of society: low, middle and high. The mainstream class in this survey was the working class with an income ranging between 500–1000 BHD per month (£875–£1750). See Figure 5-28. From this class, 88 respondents were identified, accounting for about 47% of the entire number of respondents in the sample. 49 respondents (26%) were identified as having a monthly income below 500 BHD (£875) and 41 respondents (22%) were from the highest class. Only 11 respondents, about 6%, were from the elite class with a monthly income above 2000 BHD (£3500).

The relationship with economic affordability, as shown via the monthly income data, influenced the selection of standard windows or personalised ones, as will be discussed later.



Answer Choices	Responses	
Below 500 BHD	25.93%	49
500-1000 BHD	46.56%	88
1000-2000 BHD	21.69%	41
Above 2000 BHD	5.82%	11
Total		189

Figure 5-28 The various monthly incomes of the respondents. Source: Author.

5.1.3 Interview results (3)

The 43 interviews conducted targeted academics, architects and designers, as well as 3DP specialist manufacturers in the field of global design, and regional as well as local Bahraini market specialists. Two types of interview were performed: semi-structured and unstructured. The aim was to explore the potential, aspects and validity of the SAFE values, as well as their effect as a driver in the Bahraini market. The answers were coded into themes which emerged from the collected data. Using NVivo 10 software, the codes were grouped into topics which are introduced in this section; they are further supported with relevant quotations from the interviewees' transcriptions.

Eight interviews were omitted after a quality check was run on their content. This was because they diverged from the topics discussed with regard to the themes and/or there was a lack of adequate answers to the addressed questions. In other cases, there were technical difficulties in retrieving the interview audio files, as well as the initial interviews also not being included in this research analysis.

The reliable interviews targeted three groups, as previously explained in Chapter 4 and illustrated in Figure 5-29.

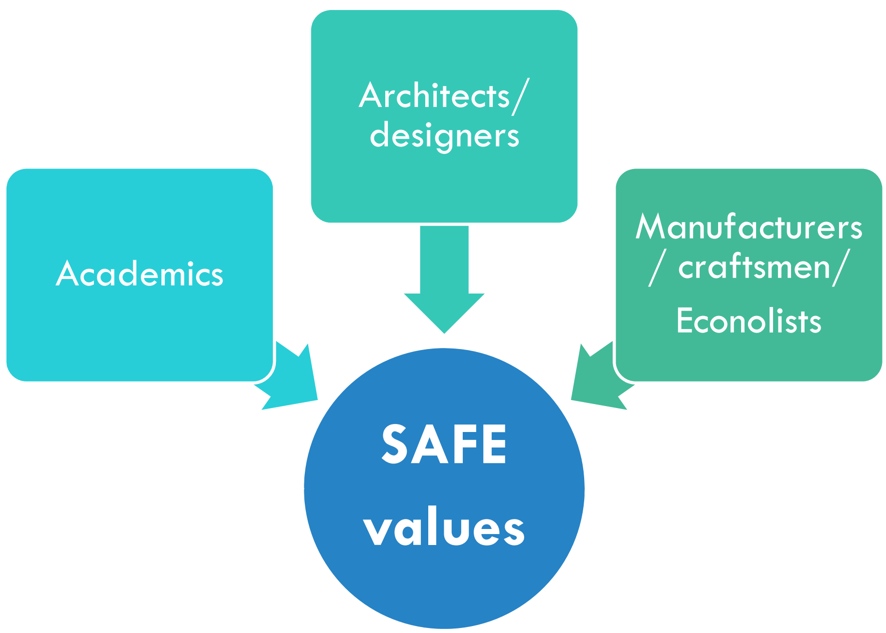


Figure 5-29: Interviewee categories. Source: Author.

Table 5-6 and Figure 5-30 present a summary of information about the interviewees and their specialities. Due to market data confidentiality and for the sake of ease of understanding of the interviewees' roles and input in the research analysis, the names of the interviewees are represented by codes. The interviewees fell under three main categories: firstly, international academics with knowledge in the context and research field (AC). Secondly, architects and designers with experience in Middle Eastern projects, and lastly were manufacturers of both 3D printing (3DS) and Mashrabiya crafts (CR).

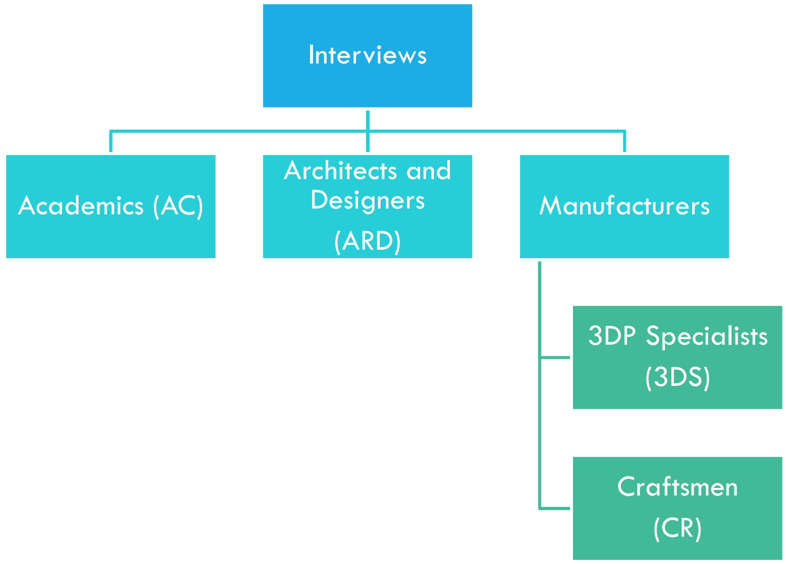


Figure 5-30: Interview type chart. Source: Author.

Table 5-6: Interview codes. Source: Author.

Criteria	Code	Number	Definition
Academics	AC	12	International and local academics who research and teach Architecture and Design in Bahrain and the Arab region.
Architects and Designers	ARD	12	Architects and designers with experience in Bahrain or the Middle East, with a minimum of 2 years' experience.
3DP Specialists	3DS	12	3DP manufacturers, economists, exhibitors and makers who deal with the 3D printing industry.
Craftsmen	CR	7	Mashrabiya craftsmen and owners or managers of gypsum and wood carpentry shops in Bahrain.
Total		43	

5.1.4 Market research to support survey and interview results (3)

The market research included obtaining data concerning 3D printing from large-scale suppliers to local wood and gypsum manufacturers for a modular screen of 1 metre by 1 metre. The aim behind acquiring these data was to compare the current local screen cost to that of a possible 3DP screen. The affordability of a screen device is highly related to its cost and the local production market. The following data represent a documentation of both the manufacturing and supply of large-scale 3DP machines to forecast possible future trends.

The data represented in this chapter were gained from market research as well as exhibitions, conferences and shows visited within the four-year period of this research (2013–2016). New machines and new prices were changing the market rapidly; new materials were also being introduced. At the TCT Show in 2013, for example, the largest 3D printing machine was the VX4000 manufactured by the German Voxceljet company. During the 2015 TCT Show there were three other large-scale printers, each competing to produce objects of above 1 metre by 1 metre from different materials and using different approaches as well as having different possible applications. Table 5-7 shows the different pricing and materials of the printers as documented in their suppliers' brochures and official webpages. See Figure 5-31.

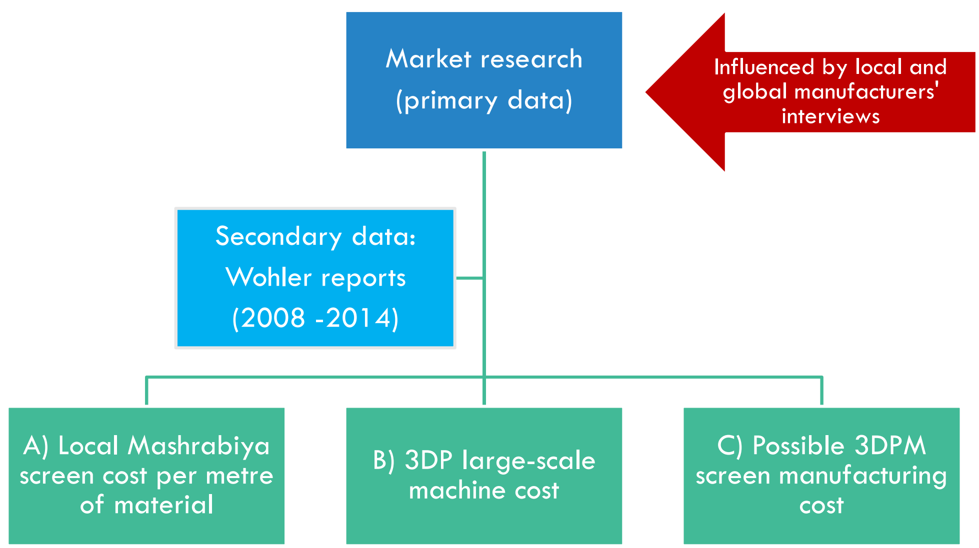


Figure 5-31: Primary and secondary data influencing market research. Source: Author.

A) **Cost of local Mashrabiya screen**

In order to run a feasibility study of current Mashrabiya manufacturing prices for manually turned solid wood, GRC and CNC screen manufacturers were contacted. The following chart (Figure 5–32) was produced according to the data given per square metre.

The lower part of the graph represents the average cost of a one metre by one metre Mashrabiya if made out of wood. Several types of wood were investigated, especially since the product would be fixed outside. Therefore, solid wood like teak was highly recommended.

However, since teak is an imported wood it has a very high cost and this can be noticed when compared to other cheaper wood types available in the Bahraini market. Other substitute materials could be used and would fulfil the privacy function of the Mashrabiya. GRC moulds, gypsum-cut boards or even aluminium Karkaris and concrete boards are considered to be much more affordable and durable options. The prices of the other materials are in the range of £280. However, these other materials cannot be as flexible or as ornamental as wood. The average cost of a teak Mashrabiya is about £1945, almost four times the price of an ordinary GRC or GRG one. See Figure 5-32.

There are five major wood workshops in Bahrain: Alnooh Carpentry, Ahmed Mohammed Jassim, Havelook, Alalawi group and Grapevine. The researcher interviewed people from four of them, which represented 80% of the market input. Alongside the major carpentries, other middle to small carpentry shops and decorative gypsum workshops were contacted. Therefore the Average Selling Price of Mashrabiya in Bahrain is £630.

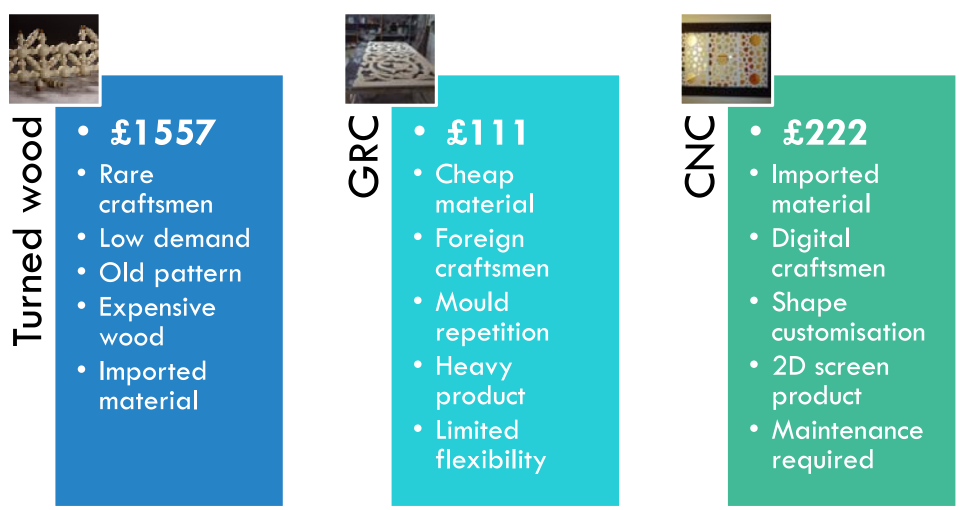
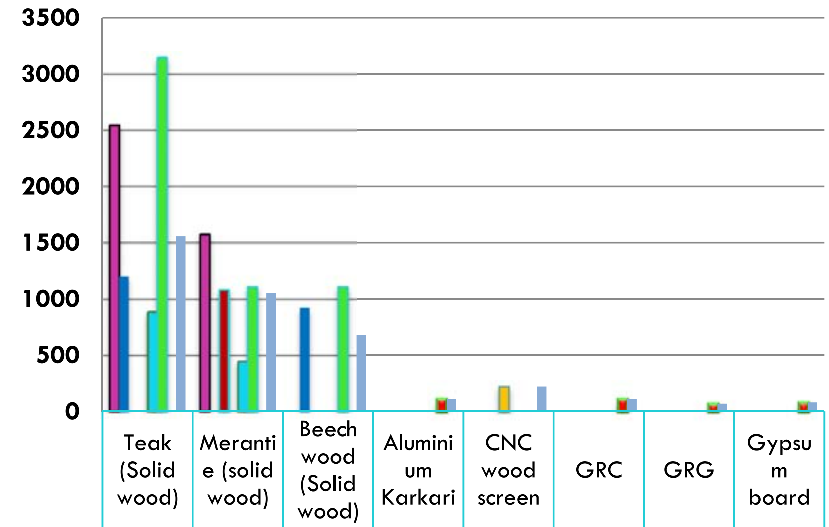


Figure 5-32: Bahraini market average Mashrabiya screen cost. Source: Author.



	Teak (Solid wood)	Meranti e (solid wood)	Beech wood (Solid wood)	Alumini um Karkari	CNC wood screen	GRC	GRG	Gypsu m board
Awal Tawers	2545	1573	0					
Galleria	1203		925					
Alshehaby	0	1083						
Grapevine					222			
Alezzah	888	445						
Haidar	3146	1110	1110					
Others				111		111	68	80
Average cost	1557	1053	679	111	222	111	68	80

Figure 5-33: Average cost of a one square metre Mashrabiya screen in GBD, figures collected in 2013–2014. Source: Author.

B) 3DP large-scale machine cost

The following table presents data on the costs gathered from secondary sources, as well as primary data gained from manufacturers. Personal communication and emails to suppliers and manufacturers quoting the cost of the 3DPM model in 2014–2016 showed variation depending on the material and machine used. The average cost of a 3DPM was above £1500 (850) BHD; the cost of the large 3DP is also summarised in Table 5-7.

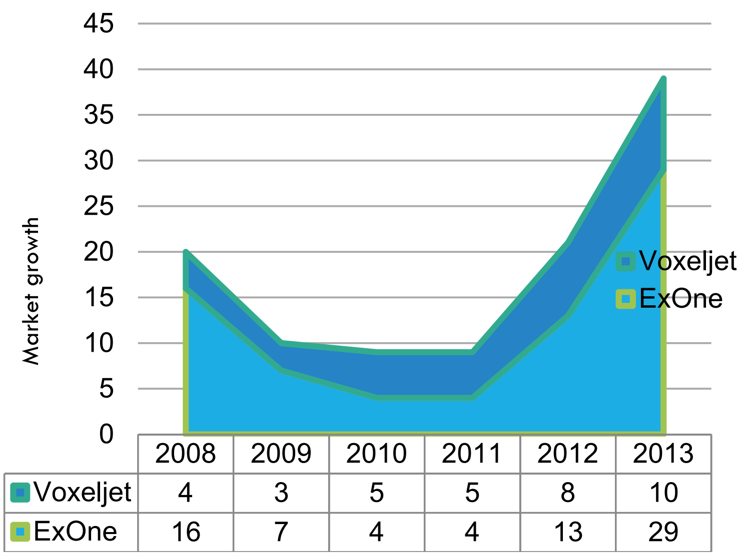
Existing research and practice related to AM processes in Construction.

	Pegna [14]	Contour Crafting	Concrete Printing	D-Shape
Process	*3D* Printing	Extrusion	Extrusion	3D Printing
Use of mould	*No*	*Yes* (Becomes a part of component)	*No*	*No*
Build material	*Sand*	• Mortar mixture for mould • Cementitious material for build	In-house Printable Concrete	Granular material (sand / stone powder)
Binder	Portland cement (activated by water)	None (Wet material extrusion and backfilling)	None (Wet material extrusion)	Chorline-based liquid
Nozzle diameter	1 mm	15 mm	9–20 mm	0.15 mm
Nozzle number	unknown	1	1	6 300
Layer thickness	unknown	13 mm [21]	6– 25 mm	4–6 mm
Reinforcement	*No*	*Yes*	*Yes*	*No*
Mechanical properties	*Tested* with zero degree (0°) of layer orientation, which means the force was given *from the top* of the printed surface			
Compressive strength	28.30 MPa	unknown	100 110 MPa	235 242 MPa
Flexural strength	14.52 MPa	unknown	12–13 MPa	14–19 MPa
Print size	>1 m dimension	>1 m dimension	>1 m dimension	>1 md dimension
Pre / Post processing	• Removal of *unused material*	• Reinforcement *per* 125 mm vertically • Backfill the mould with a cementitious material per 125 mm height	• Reinforcement after printing	• Compression of the powder for next layer by a roller with light pressure prior to the deposition • Removal of unused material
Pros	• First attempt for freeform construction	• Smooth surface by trowel	• High strengths • Minimum printing process; deposition & reinforcement	• High strengths
Cons	• Massive material placement • Removal of unused material	• Extra process (moulding) • Weak bonding between batches due to segmented backfilling batches by one hour interval	• Limited printing dimension by the printing frame, 5.4 m (L) × 4.4 m (W) × 5.4 m (H)	• Slow process • Rough surface • Limited printing dimension by the printing frame • Massive material placement • Removal of unused material

Figure 5-34 Large scale 3D printing research. Source: Lim et al. (2012).

Table 5-7: Comparison of large-scale printers according to supplier data (2015). Source: Author.

	D-Shape	Voxeljet	ExOne	3DP Platform	BigRep
Model name	D-Shape	VX4000	Max Platform	3DP Platform	BigRep One.2
Fabrication method	3D Printing	Binder Jetting	Binder Jetting	Fused Filament Fabrication (FFF)	FFF (FDM)
Maximum build volume	2000*2000* 2000 mm	4000*2000 *1000 mm	1800*1000 *700 mm	1000*1000 *500 mm	1100*1067* 1097 mm
Material	Granular material (sand I stone powder) Chorline-based liquid	PMMA (Polymethyl methacrylate), inorganic sand	Silica sand, synthetic, casting media	PLA	PLA, CoPolymere, Laywood, Laybrick, ABS, PC, PA, TPE
Approximate price (£)	186,099	988,252	1,058,586	16,540	19,849



	2008	2009	2010	2011	2012	2013
Voxeljet	4	3	5	5	8	10
ExOne	16	7	4	4	13	29

Figure 5-35: Market growth of large-scale printers. Source: Author based on Wohlers Report 2013, 2014.

C) Possible 3DPM screen manufacturing cost

The following charts represent the several types of cost included in producing a 3DPM. The final cost was calculated to be about 850 BHD (£1573) if the design was printed using an SLS printer. If it was printed using an ExOne printer then the cost would be slightly higher.

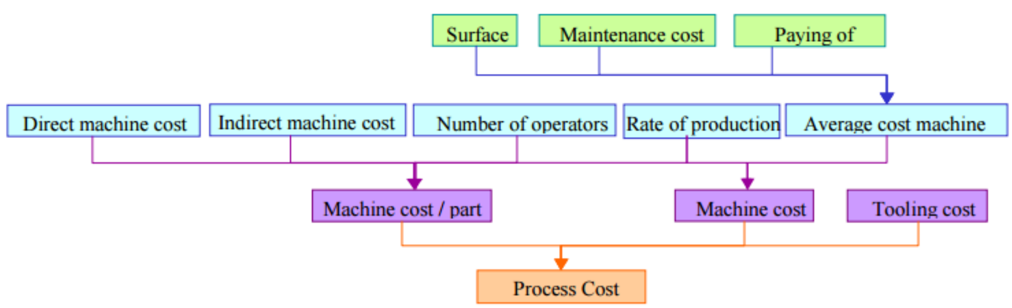


Figure 5-36: Process cost structure. Source: Perry et al. (2004, p.7).

<u>Process Cell</u>		£726678
S-Max Furan -	1026000€	£892412
<u>Accessories & Options</u>		£19123
2nd Job Box + conveyor -	126000€ (k	£10836
Ind. Vacuum cleaner -	27000€	£27835
Sand Separator -	15300€	£6516
Sand loading station -	39300€ (	£8286
Finishing Table w/cont. -	9200€	£3683
3 Sand containers -	11700€	£10623
Chemical carts -	5200€	£18415
Software tools -	15000€	
Uninterruptable PS -	26000€	
		Total £1,724,407

Figure 5-37: ExOne S-Max sand 3D printer to produce 3DPM. Source: Personal communication with ExOne.

By creating a simple business model for a possible investment in Bahrain to obtain an ExOne S-Max 3D printer, certain costs need to be taken into consideration: see Figure 5-36 and **Error! Reference source not found.** and also Table 5-8. Data are represented in Bahraini Dinars and were obtained from interviews with field specialists and manufacturers. The total cost of such an investment would be:

Machine and materials + Manufacture, land and labour = 3DPM Manufacturing in Bahrain

£1,724,407 + £7,822 = £1,732,229

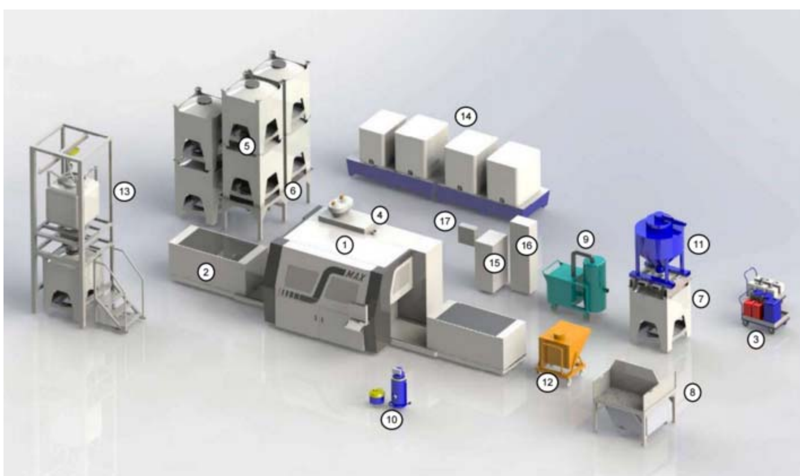


Figure 5-38: The S-Max setup from ExOne manufacturing. Source: ExOne.

Table 5-8: Cost considerations for 3DPM manufacture in Bahrain. Source: Author contribution.

	Unit charge or person salary/month in BHD	Quantity	Cost in BHD (£)
Rent of facility	2000	1	2000
Labour cost **- Manual skilled** **- Skilled/non-Bahraini** **- Bahraini**	300 300-500 500-700	1 2 1	300 800 600
- Lamra charge	5 per person 10 for more than 5 persons	3	15
- Electricity units charge	0.016	31250	500
- Water units charge	0.300	333	100
- Municipality fees	10% of rent	200	200
Total			**4515 BHD** **(£7,882)**

5.1.5 Professional focus group (PFG) (3)

The need to obtain the opinions of professionals and academics, as well as of architects and manufacturers, about the concept of the Mashrabiya model was of great importance. The professional focus group's discussion focused on the window shading device trends in traditional and modern Bahraini houses. The Bahraini manufacturing market, its growth and obstacles were also considered.

- Traditional and current window shading devices: aesthetics and functions.
- The current manufacturing market in Mashrabiya production.
- The possibilities of 3D printing on an architectural scale.
- Feedback and remarks on the concept model and visuals of 3DPM.

Table 5-9: Professional focus group members. Source: Author.

Participants	Code	Gender
Architecture academic and researcher	PFG1	M
Interior Design academic and researcher	PFG2	F
Architect	PFG3	M
Manufacturer and 3DP specialist	PFG4	M
Wood workshop manager and designer	PFG5	M
Designer and artist	PFG6	F
Total	6	4 Males and 2 Females

5.1.6 End user focus groups (3)

In order to understand whether Bahraini locals and residents would use or buy the new 3DPM, face-to-face and online focus groups were carried out in 2015; these included 42 members in total. See Table 5-10. Group sessions, organised after 8pm, took about 1 hour and 20 minutes to 1 hour and 45 minutes. Both locals and residents were invited to discuss their impressions in English and Arabic and an online app was used to ensure that a convenient time and personal location was offered to the participants. Allocated nodes ensured the validity and consistency of coding throughout the various groups.

Table 5-10: Summary chart of possible end users' focus groups. Source: Author.

Source	Title	Genre/ Language	M/F #	Engagement	Background	Nodes/ Ref.
Focus group 1	FG1	Locals/ English	2/2	Online	IT, HR, Architecture and Construction, Banking.	22/71
Focus group 2	FG2	Residents/ Arabic	4/0	Face-to-Face	Engineering, Marketing, Economics, PE.	28/68
Focus group 3	FG3	Locals/ Arabic	0/5	Online	Engineering, Law, IT, Psychology.	26/122
Focus group 4	FG4	Locals/ Arabic	0/3	Online	Statistics, Architecture, Social Science.	22/53
Focus group 5	FG5	Locals/ English	1/3	Online	Architecture, PE, Interior Design, Product Design.	25/117
Focus group 6	FG6	Locals/ Arabic	0/4	Online	Business, Interior Design, Marketing, Finance.	20/87
Focus group 7	FG7	Locals/ Arabic	2/3	Online	Architecture, Health, Interior Design, Finance.	30/152
Focus group 8	FG8	Locals/ English	1/4	Online	IT, Commerce, Interior Design, HR.	27/120
Focus group 9	FG9	Locals/ Residents/ English	2/3	Online	HR, Finance, Banking, Interior Design, Architecture.	19/113
Focus group 10	FG10	Residents/ English	1/1	Face-to-Face	English Literature, Biochemistry.	19/45

5.2 METAPHOR ANALYSIS

In order to understand the meaning behind the findings and collected data in phases 1, 2 and 3, it was essential to use open coding. Open coding can generate a general sense of the main subjects and themes that might evolve later to form the main nodes and sub-nodes of thematic analysis. Yet it is equally essential to understand how the respondents explained and responded to two major topics in this research. Firstly, it was essential to understand how they perceived architecture and housing design in general and what metaphors were mostly used to describe the trends, styles and forms of housing and architecture in Bahrain. The second part of this research sought to understand and investigate the responses of the population and the manufacturers, as well as architects and designers, to the idea of a 3D-printed Mashrabiya using 3DPM.

The common steps in analysing metaphors are outlined by Charteris-Black (2004). It starts with identification, then interpretation and finally explanation of conceptual metaphors. Metaphor identification involves, firstly, a close reading of a sample of texts to identify candidate metaphors. These hypothetical metaphors have metaphoric potential. Lee (2015) suggests that these metaphors can only be confirmed as metaphors through detailed qualitative analysis. The second step is metaphor identification through a major examination of the context. Key-words are defined by Charteris-Black (2004, p.12) as those "words that have a tendency to be used as conventional metaphors". Thirdly, metaphor interpretation includes ascertaining the extent to which a metaphor is determined by pragmatic and cognitive factors (Charteris-Black, 2004). This involves identifying conceptual metaphors and considering the extent to which metaphor choices account for constructing a socially important representation. The semantic tensions found in the metaphoric expressions revolving around the proposition of Singapore as a small, vulnerable state lacking in natural resources, for example, take on the evaluative meanings of the metaphor owners and producers that it is essential to work hard and stand united as a nation, and to get behind the government leading the nation.

While coding SAFE values it was evident that certain words kept repeating in relation to housing design as a context and 3DPM as an object. Therefore, by adopting the ideas in both Charteris-Black (2004) and Lee (2015) the following metaphor analysis was conducted. The aim was to look for common problems and identify words that reflect a certain mindset and the social as well as style preferences of Bahraini locals and residents. This can contribute to understanding the users of future Mashrabiya.

5.2.1 Housing design

In the discussions in the interviews and focus groups the topics revolved around housing design in general and Mashrabiya in particular. Table 5-11 presents examples from the influential metaphors found while analysing the collected data under the housing design code while Figure 5-39 presents the sources of the majority of the metaphors. The figure also indicates how can data be collected and coded from different evidences in the collected data set. 35% of metaphors were offered by the interviewed academics and scholars, and about 25% of the answers given by the architects and designers within legal or regional architectural practices.

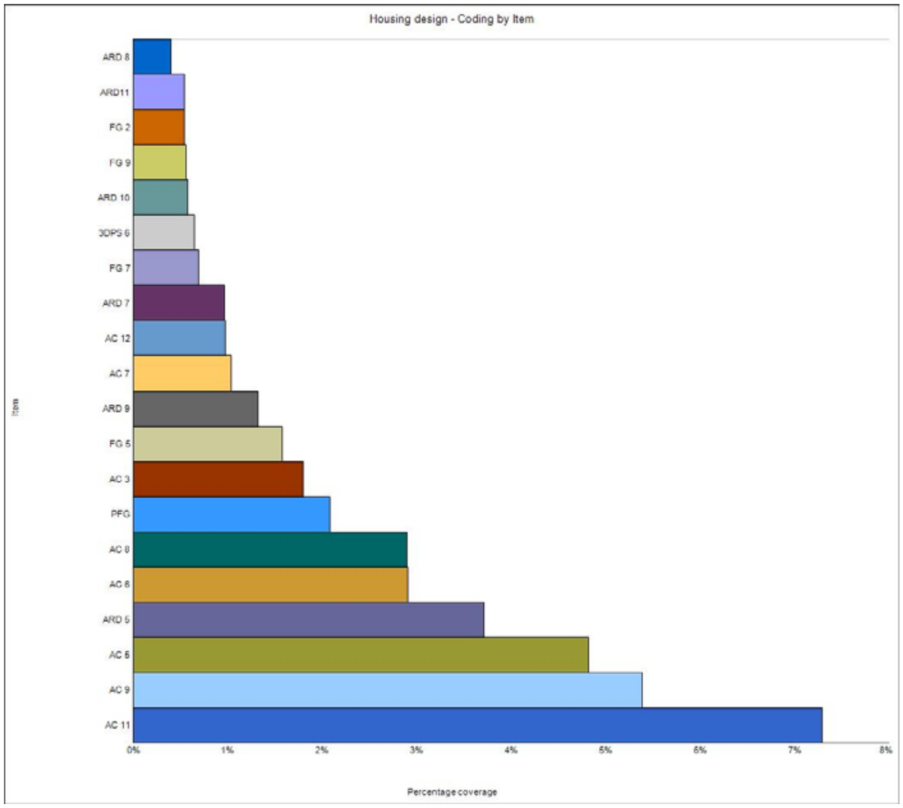


Figure 5-39: Housing design metaphors from research participants. Source: Author.

Various metaphorical aspects were elicited from the collected data in the context of housing design. Data ranged from discussing trends in architecture and housing styles, their identity and the problems currently being faced, as well as possible solutions. The participants used a mixture of metaphors and idioms as well as examples to explain their ideas.

Bahrain, as with other oil-economy based countries, has witnessed a transformation in its architecture, and therefore new architectural trends have appeared. However, the current scene represents a 'strong public style conflict', as explained by a PFG member. Currently, the exteriors of houses and the predominant building style is a mixture of minimalist designs and eclectic blends of contemporary and modern facades with a touch of traditional or Western elements. A balanced solution between the two cannot yet be identified.

To be more specific, the facade has always been an indicator of the owner's wealth and status. In traditional houses, elaborated shading devices, for example, were crafted by foreign craftsmen, as AC11 indicated. Nowadays, this link still exists as 12 interviewees and group members indicated this. Interviewee AC5 related these architectural expressions to 'individualism, extravagance and exhibitionism', which are phenomena that are evident in the selection of facades and furniture styles. FG7, FG8 and FG9 used metaphors to express the importance of such facades and interiors and their effect on the person looking at them, as well as the link between this and the owner's income. FG2 and FG5 also related the current architecture and the style of interiors to money. This raises the value of such stylish architectural facades as something that is to be appreciated by the neighbourhood, as AC9 explained. This high value given to the appearance of the exterior facade can lead owners sometimes to 'exaggerate' its details, as ARD9 noted. This can lead to a willingness to construct a desired image, even if it does not function correctly (AC5).

Table 5-11: Sample of metaphors and idioms used to express exhibitionist phenomena. Source: Author.

Metaphor/ idiom	**Coded in**
'***Showing** off and **arrogance**'*	FG2
*' money can't **buy style** but **style** does **require money**'*	FG5
*'**obsessed**'*	FG7
*'**extraordinary** look'*	FG8
*'**eye catching**'*	FG8
*show certain '**prestige**'*	AC9

Exhibitionism is not favoured by the Islamic culture and its rules which prefer simplicity and modesty. So, in inward-oriented courtyard houses that distil exhibitionism, new and different cultural shifts have appeared. New architectural trends, combined with outward-facing houses, are a result of new regulations and exposure to the world while travelling or web surfing; these aspects have created new forms and dilemmas. FG7 described the current situation as a 'culture invasion' and FG8 expressed the situation as a 'bottleneck'. The negative impression he expressed relates to the influence seen in trends that combine Western architecture with features such as large areas of reflective glass and bare windows in a conservative community. While this trend started with the elite, another academic in PFG justified it as a 'trickle down' effect. The social phenomena of trickle down is known to be the act of people in the lower social order who imitate the acts and style of those in the higher class in an attempt to be the same. So an investigation is needed to understand who the trend setters are.

Besides exhibitionism and the cultural shift, current housing architecture in Bahrain suffers from another major problem related to new cultural preferences. The 'copy and pasting' design process has caused a loss of identity and the functional form of Bahraini houses. 12 metaphors and idioms were found under this node using words like: copying, cutting and pasting, imitating. However, the problem itself can be divided into three disruptive acts, described below:

Copying forms from Western architecture

The act of copying forms from Western architecture and pasting them into a hot humid climate such as that of Bahrain. This is partially the fault of the architects who long to satisfy their clients and do not waste time designing outside their '*comfort zone*' (PFG). As a result, housing architecture in Bahrain now is '*mass produced*' as AC11 asserted. Nevertheless, it is also partially the client responsibility and desire that need to be catered for by the architects as raised by PFG member.

Electing forms

The second is the act of electing and merging between Western architecture and modern forms, and then compromising the design with traditional architectural elements and touches. AC11 explained it as a form of '*playing with the nostalgic part*' while PFG member likened it to a '*form of Schizophrenia*'.

The dilemma of rejecting new ideas

The third act is related to the mindsets of Bahraini residents in their rejection of new ideas, especially if these ideas try to bring a hybrid solution to the architectural scene. However, once these ideas are implemented, they have '*a domino effect*', as noted by a PFG member. This then spreads and the idea is replicated in a new neighbourhood.

The copying problem relates to another struggle to find an identity and a style that serves both environmental and aesthetic purposes. The latter problem might be strongly connected to the unrealistic and illogical decisions house owners sometimes take in selecting and styling their homes as a result of the influence of Western design and their own desire for exhibitionism. While this may not be the case with all Bahraini residents, other neighbouring Arabian Gulf countries are experiencing the same problem. The interviewee and group members called for essential acts to be undertaken. These were coded into 58 nodes and summarised in Table 5-12 which follows.

Table 5-12: Essential acts required. Source: Author.

		by			by
1	*'Building should fit purpose'*	FG2	**9**	*'Trending in architecture takes a longer period of time'*	PFG
2	*'Blend with surrounding environment but still stand out'*	FG5	**10**	*'Transfer the trend into need'*	PFG
3	*'Interior should connect (occupant) physically and emotionally to the surrounding'*	FG5	**11**	*'Architecture is not something that exists in a vacuum'*	AC11
4	*'Movement should encourage traditional style based architecture'*	FG7	**12**	*'Understand newly emerged requirements'*	AC6
5	*'Seek privacy in a variety of new ways'*	PFG	**13**	*Need for a 'holistic approach' to architecture design*	ARD9
6	*'People playing around with the regulations'*	PFG	**14**	*'Painkiller' solutions might work*	ARD9
7	*'… Rather than acting impulsively, design will come naturally'*	PFG	**15**	*Need 'icons of identity' projects*	ARD5
8	*Understand the 'shifting concept of beauty' in new design proposals*	PFG	**16**	*'Hybrid houses' as future solutions*	AC11

From housing design in general to shading devices in particular, more nodes were aggregated that defined their function, aesthetic role and their decreased use. ARD5 explained the role of shaded balconies in creating pleasant '*subtractions and additions*' to the building mass. Mashrabiyas in particular were a '*3-in-1*' (PFG) device that were used in openings to serve privacy, daylight penetration and allow a '*link*' (ARD5) to the urban space they overlooked. AC5 supported this by stating that facade treatments used to be based on the '*extraction of privacy*'. Nevertheless, a common remark was made about suppressing the use of shading devices in modern houses. PFG members noticed that there was no '*real elaborated emphasis*' on shading devices in general in Gulf and Bahraini architecture. Another remark was also made regarding the lack of an '*inherited attitude*' to externally shaded windows with vertical or horizontal shading devices.

Between architectural dilemmas and the undervaluing of shading devices, participants emphasised the role of '*awareness*' (PFG) in adopting new solutions. Other issues that were also mentioned that should be taken into consideration were: '*low electricity tariff*' (AC11), '*global warming*' (AC6), '*mindsets*' (PFG) and '*noise pollution*' (AC11). More explicit analysis of these problems is included in their relevant theme which is explained in section 5.4.

5.2.2 3D-printed Mashrabiya (3DPM): From research to practice

Figure 5-40 and Figure 5-41 present the cycle of the development of the 3D-printed Mashrabiya screen during the research design practice. Each cycle stage represents the creation of a new form and the computer modelling programs associated with it, as well as an indication of the 3D printer used to produce the 3DPM concept or product. One of the possible stages was excluded due to time limits and the lack of the necessary technical support. These stages were explained in 4.4.1.

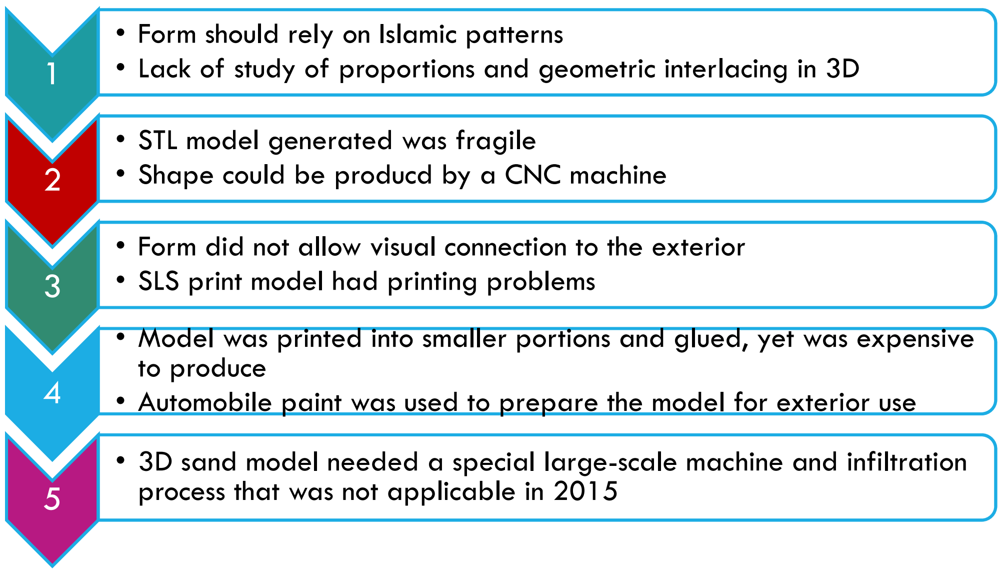


Figure 5-40: Challenges faced during analysis of concept model. Source: Author.

The production of a Mashrabiya sand model is considered a research accomplishment. This is because the material has never been used to 3D print structure parts, even if they were non-load-bearing ones. The model produced by ExOne uses a technique that was originally used to create sand moulds for other metal parts of an industrial scale. Nevertheless, the size of their build area can be used for architectural elements like Mashrabiya, as the bed size for their Exerial machine is larger than any other manufacturing machine (W2200 by D1200 by H 700cm). While the material used is silica sand, other possible new materials are being developed every day; these include carbon fibres, ceramic sand and even salt.

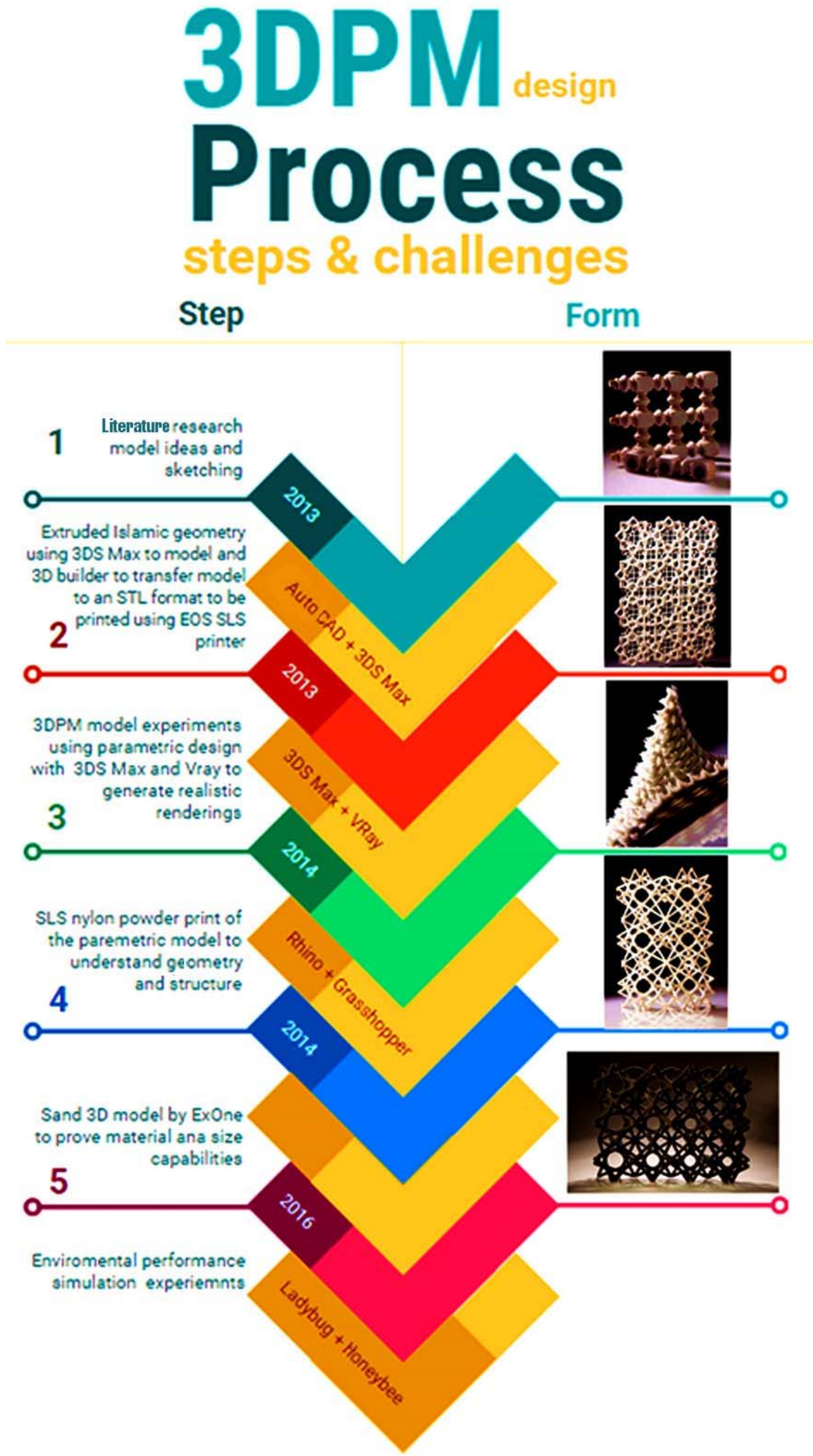


Figure 5-41: 3DPM design development steps. Source: Author

During the data collection, the partial 3DPM proof-of-concept model, illustrated in step 4 of Figure 5-41, was rendered using 3ds Max to give a real interior and exterior view of the concept. Focus group members, architects and craftsmen, as well as some 3D specialists, were presented with these realistic renderings and certain metaphors and words appeared in coding their responses to the form. An example of this model can be seen in Figure 5-42.

The bold words in Table 5-13 explain how the respondents described the 3DPM design. Most of them agreed that it was a combination of old and modern designs that could reflect identity and was a sort of a cliché of a traditional classic architectural element. The reintroduction of old architectural elements as a minimalist product was also favoured as an '*accessory*' (FG5) and an '*alternative*' (FG4) to current interior shading products. They also acknowledged that the 3D pattern gave an interesting shadow effect to the interior and allowed vivid moonlight to penetrate the room at night. Negative feedback was received from others, however, who described the geometry as an industrial one or one that resembled knitting.

Nevertheless, from a manufacturing and architectural point of view, the concept proved to be viewed as a very interesting application. Architecture-wise, an expert forecast that this could '*transform architecture*' (PFG), especially for 3D printing which always seeks useful content. Other craftsmen supported this style of Mashrabiya making and asserted that it might be the way forward for craft-based architectural products that lack skilled craftsmen.

The complexity of the design and its manufacturing, however, might attract a niche market and be bought only by customers who seek style and bespoke designs regardless of their cost. Therefore, mass customisation for such clients should not only satisfy their tastes but give them a unique personal design as one of its kind. This would not only require a high income but also an adventurous personality that could afford '*caviar over fish*' (FG5).

Figure 5-42 Realistic rendering of sand 3DPM produced using 3ds Max. Source: Author rendered by DPI.

Table 5-13: 3DPM metaphor coding. Source: Author.

	Metaphor/ Phrase	By
1	'*The different sizing of interstices creates a **fluid illusion** resembling water*' '*like a **bespoke** design*'	FG1
2	'*target high-end customers*'	FG3
3	'*great **alternative** to traditional curtains*'	FG4
4	'*style … a bit **industrial***' '*interesting **effect***' '***classical** touch, traditional classical **touch***' '*treated as **accessories***' '*so **raw***' '*Not new idea but a **forgotten beautiful** old idea that needs to be **reintroduced***' '*I think the idea is a **great** one and one of its kind but it's **like eating** fish or **caviar**… they both come from the sea, end up being served on a plate and eaten … some people will be very **thrifty** while others will be **adventurous** and try something **new** …*'	FG5
5	'***shadow** patterns effect **projected** into the house interior*' '*I think its effectiveness at **night** would be **excellent** especially if it **allowed moon light** into the room. (Emotional face)*'	FG7
6	'*add **identity** and **character** to the exterior*' '***unique***'	FG8
7	'***elegant***' '*pattern is taking a **3D** form **not** a **2D** form*' '*gives **depth** to Mashrabiya design*' '***modern minimalist** taste*' '***combination** of **modern** designing with the touch of the **past***' '***cool***'	FG9
8	'*Reminds me of **Knitting**,… **cliché***'	FG10
9	'***3-in-1***' '*… a product can be **adapted** to **different** uses*' '*have a very small **niche** market*' '*as the **thin line** between **exterior** and **interior***' '***This** is what can **transform** architecture*'	PFG
10	'*3D printing seeks **useful content***' '*very **interesting** application area*'	3DSP 3
11	'*3DPM **absolutely** makes **sense***'	3DSP 4
12	'*it really **depends** if you have a customer that wants to **pay** for it…. and if you can make a **design** that is really **unique** and **extraordinary***'	3DSP 8
13	'*While we like to hold on to the human heritage I think what you are proposing is the next **way forward***'	CR6

5.3 THEMATIC ANALYSIS OF DATA

Since the aim of this research is to validate a holistic approach to the use of 3D printing in reviving Mashrabiya screens, SAFE value (Social, Aesthetic, Functional and Economic) constraints were coded as main themes. Below each theme, new sub-themes emerged while coding the collected data.

Where some data sources and codes mediated between two themes, they were interpreted in their context of relevance to the code. The flexibility of the thematic analysis, as advised by Braun and Clark (2006), helped in creating relations and correlations between heading themes and also sub-themes. Corbin and Straus (2008), cited in Bazley and Jakson (2013, p. 70), define a code as "an abstract representation of an object or phenomenon". Bernard and Rayan (2010) also suggest that coding can be a way to identify themes within textual data. Therefore, this was the most suitable type of analysis to deal with the different data types obtained from the implemented methods.

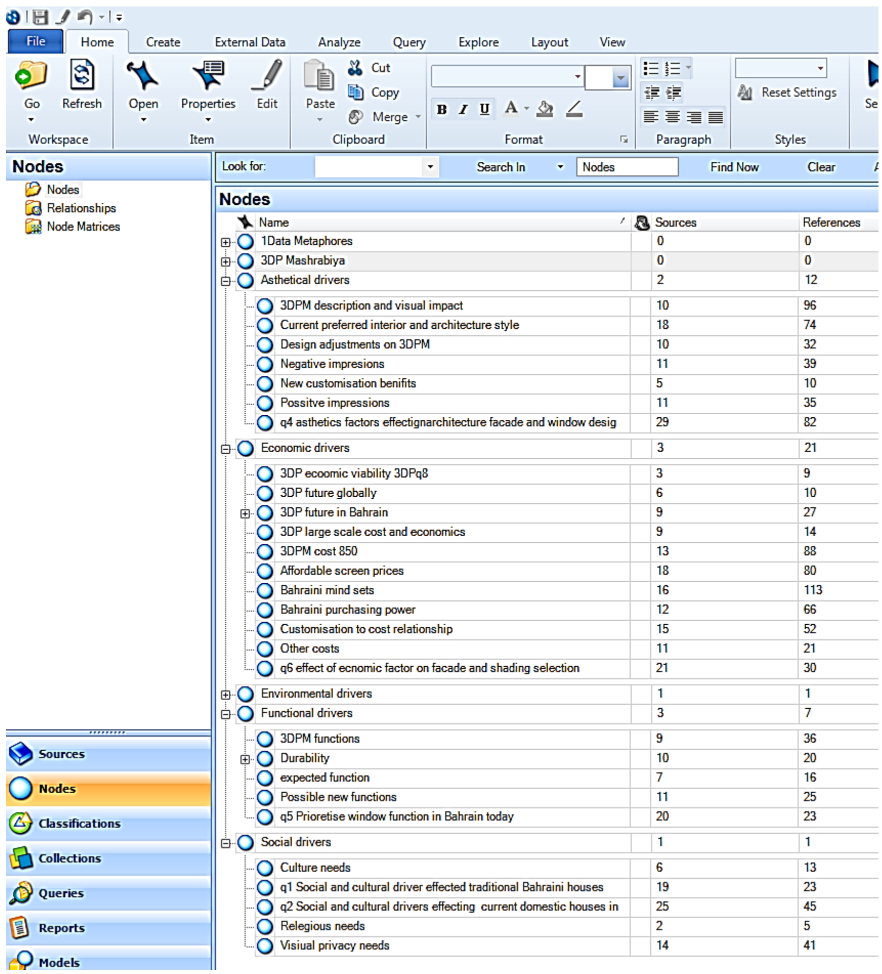


Figure 5-43: Partial Nvivo window showing the coding frequency of nodes under each theme. Source: Author.

A general representation of the node coding of information among the major themes and their subheadings is shown in Figure 5-45. It is evident from the visual percentages that the rebalanced data codes among the major themes related to SAFE values. Economic codes were the most frequently used at about 25%, followed by Aesthetic codes (18%) and then Social and Functional codes, accounting for nearly 9% and 8%, respectively. The reason behind the lack of focus on this area is that other researchers, such as Aljawder (2014) and Karamata and Andersen (2014), included them in their research. However, it can be noted that environmental drivers, for example, were coded first by about 3% of the total sample but, because of the lack of sufficient data in the area, these were included under the functional theme along with sustainability.

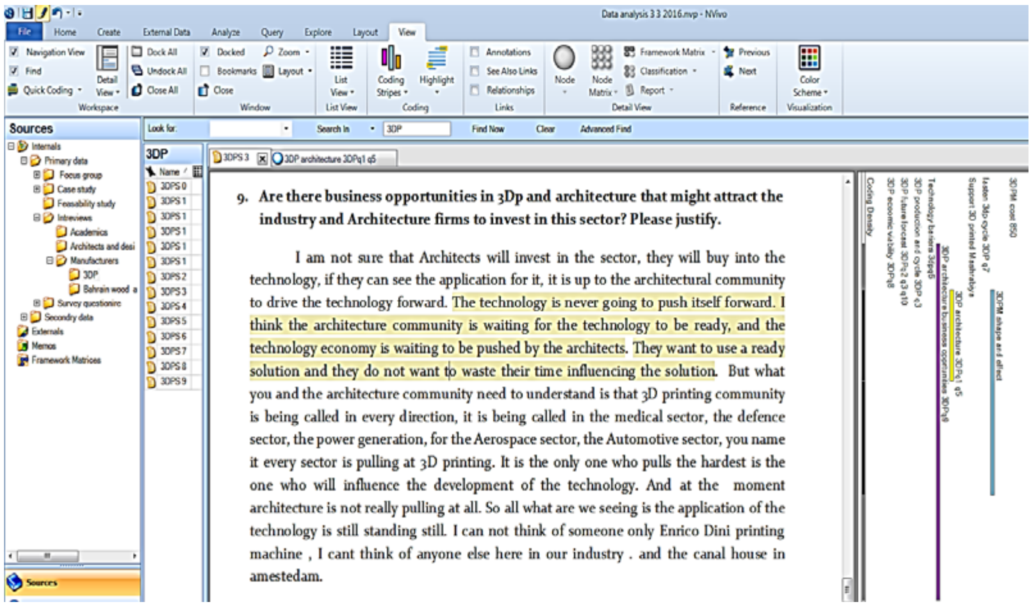
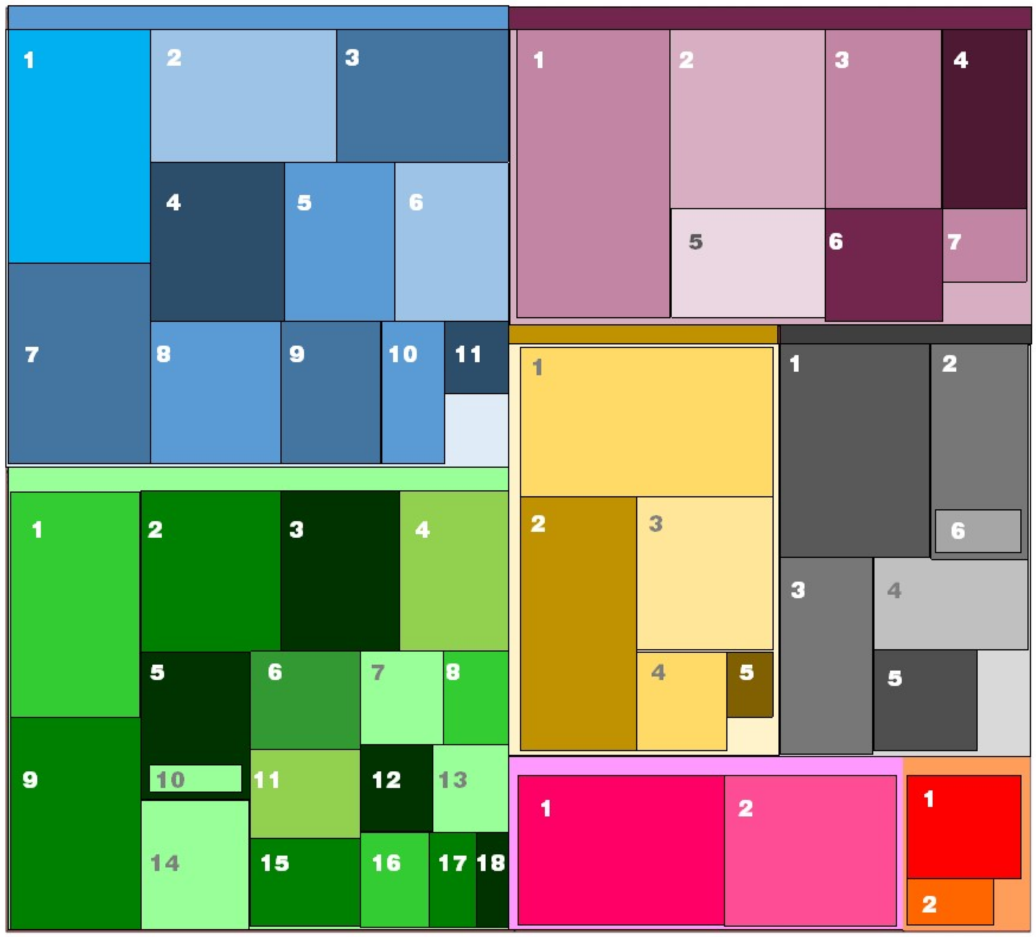


Figure 5-44 Coding stripes (right) showing where source passage text was coded under multiple nodes. Source: Author



3DP Mashrabiya

1. Factors effecting window shading
2. Support 3DPM
3. 3DPM future forecast
4. 3DP technology barriers
5. 3DP for architecture
6. 3DP materials and machine
7. GCC manufacturing market
8. 3DP production
9. Current manufacturing market
10. 3DP architecture business
11. Against 3DPM
12. Craft of Mashrabiya
13. 3DP product cycle speed
14. Façade specifications
15. Future manufacturing market
16. Support 3DPM

Economic value

1. Economic effect on façade selection.
2. Bahraini mindsets
3. Customisation to cost relation-ship
4. 3DPM cost
5. 3DPM future in Bahrain
6. Other costs
7. Affordable screen prices
8. Users' purchasing power
9. 3DP large scale cost
10. 3DP future globally
11. 3DP economic forecasts

Social value

1. Socio-cultural drivers effecting current domestic houses
2. Socio-cultural drivers effecting traditional domestic buildings.
3. Visual privacy needs
4. Culture needs
5. Religious needs

Aesthetic value

1. Aesthetics effecting interior and architecture
2. current preferred style
3. Positive impressions about 3DPM
4. 3DPM descriptions
5. Negative impressions
6. Design adjustment to 3DPM

Functional value

1. Window function priorities
2. Durability
3. Possible new function for 3DPM
4. 3DPM functions
5. Expected functions

Environmental values

1. Environmental considerations
2. Sustainability

Metaphor analysis

1. Housing design
2. 3DPM shape and effect

Figure 5-45: Thematic nodes compared with the number of items coded using Nvivo 10 explore tool. Source: Author.

5.3.1 The social value theme

- **Social and cultural drivers affecting traditional houses**
  1. Visual privacy was considered by all respondents to be the major influence in Bahraini Islamic culture.
  2. Veiling the women of the house and concealing the family's daily activities were religious and traditional requirements. This was ensured by an inward house orientation, courtyards and window shading devices, as noted by AC9 and AC10. This made sure that foreign male eyes could not pry into the core of the house.
  3. Past architects provided smart solutions by providing window veils or screens. Their emphasis was on balancing visual privacy through windows while admitting enough daylight.
  4. The characteristic of the community for hospitality and the closed neighbourhoods strengthen social relationships yet emphasise segregation between men and women in the public spaces within a house as well as '*demarcation*' (AC7) between gathering spaces.
  5. AC4 and AC5 asserted that traditional Bahraini houses were an outcome of adherence to local traditions based on Islam.
  6. Since families tended to be extended ones, it was highly important and a driving force to control urban morphologies and this shaped traditional houses, as concluded by AC5and ARD11. Collaboration within these extended families, as well as the close relationships within the neighbourhood, also played a vital role.
  7. The value of neighbourhood appreciation is also evident in the layout and treatment of communal spaces within a traditional house.

- **Social and cultural drivers affecting modern houses**
  1. It can be claimed, according to architects and academics, that the trends of Westernisation and modernisation have affected young people and caused them to lose some of their cultural values. PFG members still see a form of attachment to identity and culture but the enjoyment of being in modern settings has shifted the balance. AC12 and AC2 were sure that people have started to care less about visual privacy, for example.
  2. The will to preserve heritage and identity is an evident goal of most Gulf cities in the region. However, no such actions can be seen directly in their current architecture as this can be described, along with that of other GCC countries, as '*faceless*' (AC9).
  3. '*Showing off and exhibitionism*' (AC4, FG2 and AC8) are noticeable cultural values currently existing in Bahrain. These are reflected in the selection of architectural

elements, interior style, materials and finishing. Yet, in general, a '*conservative culture*' (ARD11) does not describe the entire community today.

4. Economic status and '*socio-economic factors*' (AC4) are dominating factors; this was evident both before and after the oil era in Bahrain.
5. The 'trickle down' social phenomenon influences modern society and its houses, as pinpointed in PFG. People from the lower social class imitate the trends of the upper, richer social class in a race to attain their status.
6. Social habits change with time and income, as well as through exposure to social media and this affects the design preferences of residents. However, a practical design should not respond to trends and should stay practical, even if the trend dies out after a while or is suppressed by a new trend (FG5). Another opinion highlighted the influence of trend setters and said that the design of modern homes should respond to the trend setters (PFG).
7. Two contrasting social attitudes also emerged. One would copy designs of interest from neighbouring buildings, which was described as having a '*domino effect*' (PFG) in its replication. Another attitude would reject the replication of design elements because everyone would then be doing the same thing at a certain time.
8. The lack of social and cultural drivers in design are argued to be the consequence of the cultural invasion that has affected designers, architects and the tastes of the general public. Nevertheless, some development projects, such as Deyar Almuharaq, were claimed by FG7 to pioneer hybrid compositions that revive the sense of neighbourhood cultural values.
9. The use of Mashrabiyas was argued by PFG to have more of a social and aesthetic effect rather than a religious one in modern houses, as drawing a curtain could do the same job as a Mashrabiya nowadays.
10. New building regulations force houses to be set back about two metres and this led to buildings with smaller areas. Consequently, people have started to favour an outward orientation to maximise the building area and to follow modern housing trends.
11. Social and cultural values are much more appreciated by people who have lived and been raised in traditional houses, or by architects and designers who aspire to appreciate traditions.
12. A call to educate and increase people's awareness was made by a few participants in FG7 about the importance of conserving '*cultural legacy*' values in their architecture.
13. The need for catalyst projects or buildings that combine both traditional values and modern architecture was argued to be highly important. These projects could be referred to when explaining such situations.

14. AC11 offered suggestions regarding current social factors and architecture. He demanded that good ideas should be incorporated into housing projects. He defined good ideas in terms of '*improving the social cohesion of the family*', '*the relationship between indoor and outdoor spaces*' and to '*stop isolation forcing people to live in bubbles*' within their own rooms or cars.

- **Visual privacy, and the cultural and religious needs of targeted 3DPM users**

1. The religion of Islam emphasises communality and social dependence while maintaining strict arrangements for privacy between insiders and outsiders, as well as between women and men.
2. Bahraini locals and expats require different levels of visual privacy. Conservative families in Bahrain, like the original Arabs and the more religious families, pay major attention to privacy and window shading. While some might allow a vague shape to appear behind curtains, the majority would ensure that not even the shadows or lights of the interior space behind the curtains could be seen. Consequently, reflected glass needs thick interior shading, particularly at night when the room is exposed to outsiders.
3. Mashrabiya can ensure visual privacy; they also reflect the Islamic culture and allow ventilation at night, as noted by FG7 members. Four members did not feel that the new 3DPM ensured privacy in its design. FG9 members supported the new 3DPM, however, acknowledging that both privacy and shading can be provided to the interior.
4. The Muslim married men who were interviewed were clearly more aware and sensitive to the issue of privacy. Muslim men are known for their jealous character and protective attitudes towards the females of their family, and this was evident in FG9 and 7.
5. People still want privacy but in a variety of new ways. A balanced solution between cultural demands and modern architecture is needed, as suggested by AC1.
6. ARD4 stated that culture and religious values, along with education and the financial situation of house owners, direct their appreciation to architecture and shading as well as the environment. He mentioned that people coming from villages value their privacy more than those from cities. Ultimately, though, if the window is stylish, they will ignore the privacy factor. But he also asserted that, in general, Bahrainis appreciate their visual privacy for cultural reasons rather than religious ones.
7. In Bahrain local individuals cannot just open their windows at dawn and be exposed to other people. PFG members declared that it is both culturally and religiously

unacceptable, even if the individuals are not very committed to the Islamic religion. This is why many of the balconies have been abandoned as well.

8. In predicting the future in Bahrain and the Gulf countries, ARD9 thought that cultural aspects would '*go away*' and '*new values*' would come into play.
9. In her research survey about daylight and visual privacy within Bahraini houses, Aljawder (2014) made some important conclusions. She found that a need still exists for visual privacy, yet the drivers behind this need range between religious beliefs, cultural factors and personal preferences. She also discovered from the contradicting viewpoints she received that religious beliefs are more dominant in the need for visual privacy. She showed that about 30% of the survey respondents considered visual privacy as much more important to them when compared to daylight.
10. Sidawi's (2012) survey about the values of Mashrabiya in Saudi Arabia can be relevant to Bahrain as both nations share similar religious and environmental conditions. He concluded that Mashrabiya on a global level express meanings concerning the environment and architecture that are appreciated more than the social value of Mashrabiya. More explicit meanings are listed under social values, as can be seen in Figure 5-46.

Potential embedded meanings and values	Mean	Std. Deviation	Skewness
Environmental			
It provides a comfortable internal environment in terms of light distribution density etc	3.9429	0.84931	-0.766
It provides a comfortable internal environment in terms of thermal and environmental comfort	3.7101	1.04461	-0.821
It protects passer-by from sun and rain	3.3385	1.17629	-0.698
Mean (environmental)	3.6638333		
Psychological			
It increases sense of self-esteem and happiness of the house's inhabitants	3.0469	1.11881	-0.165
It provides a relaxing and peaceful internal environment	3.8676	1.11843	-0.984
It is pleasant to the eye, humanely-scaled	3.9	0.9033	-0.77
It helps in increasing the attachment/ bonding of an inhabitant to the house	2.4138	1.19992	0.337
It is inspiring and motivates imagination	3.5507	0.89994	-0.343
Mean (Psychological)	3.3558		
Social			
The big size of al mashrabiyah is an indication of prosperity, power, high social class and dignity of the inhabitants	3.8841	1.21916	-0.925
It gives a clear indication of the identity of the house's occupants	4.0588	1.02042	-1.163
It stimulates and preserves the privacy of inhabitants	3.942	1.06942	-0.922
It facilitates inhabitants' communications with the outside world in a conservative way	3.791	1.09458	-0.784
It helps in preserving the inhabitants' safety	3.0746	1.27105	-0.235
It preserves a delicate connection of passers-by with the inhabitants in terms of transmission of sound and smell	3	1.06904	0
It preserves a delicate connection of inhabitants with the alleyway in terms of transmission of sound and smell	2.9231	0.9732	-0.052
Mean (Social)	3.5248		
Spiritual			
Its' ornamented patterns hold Islamic spiritual meanings			

Figure 5-46: Sidawi (2012); Meaning of Mashrabiya: partial survey results, p.14.

5.3.2 The aesthetic value theme

- **Current preferred interior and architectural style in Bahrain:**
  The rise of the mixed style as one of the top preferred styles in fashion today (2015).

1. The preferred designs and styles varied among the respondents' answers. The largest group (33%) of the 42 focus group members adored modern-style architecture and interiors. Only 10% preferred the classical style, but the new style that combines principles of modernity with touches of the classical style was favoured by 24%; a few even called it the current style which was now in fashion. A purely practical and minimalist style was favoured by 10% of the respondents.
2. There was a lack of a definition and name for the style that combined and mixed both modern interiors and architecture with touches of classical elements, and respondents had a fuzzy image of it. Phrases like '*touch*', '*twist*', '*influence*' and '*combine*' were used to describe the new hybrid style.
3. A lack of consideration regarding Bahrain's identity and conservation of its heritage image was seen during the style selection. None of the respondents chose a Bahraini style or even defined an element that existed historically and could be re-interpreted in his/her style selection. Only three members preferred an influence of traditional heritage elements, Islamic patterns or Arabesque motifs.
4. Less attention was given to simple and practical designs that could withstand heat and humidity.
5. Male participants highlighted the importance of considering practicality, materiality, context and environmental efficiency during their design and style selection.
6. Female participants focused on describing the aesthetics of their interior as well as privacy; the practicality of shading and its environmental functionality were not a priority.
7. Aljawder's (2014) findings support this by stating that about 50% of her survey respondents preferred a modern style and the other 50% seemed still to want a mix of traditional touches.
8. A lack of awareness was evident in terms of considering the environment, the weather and the effect of air conditioning on housing design.
9. The source of the architectural style might be the architect, the nearby neighbours, family and friends, web surfing international architecture (Western examples in particular), or a combination of all of these factors.

10. There is a mistaken attitude to copy-paste images into current architecture and a recommendation was made to understand the constraints and heritage and then come up with

new forms and new possible functions, as well as considering the use of new materials in a holistic approach.

- **Aesthetic factor affecting the style of architecture, window designs and shading: Large durable window treatments with closed curtains and maybe decorative screens**

1. Clients' aspirations, market materials, environmental factors, land dimensions and masses constrain architectural housing design.
2. The majority preferred simple unshaded windows with fixed glass, as shading options are looked at as being restricted to uninteresting forms. Some have never even thought of covering them from the exterior.
3. Interior-wise, curtains and blackouts remain the constant solution for ensuring privacy and controlling sunlight.
4. Some architects prefer blending styles and using window designs of that particular style in their projects' facades, like Moroccan-style windows.
5. Shading should be made from a material that is durable and resists humidity and dust; it also must not ruin the house's facade over time.
6. Selecting windows, frames and shading that require less frequent maintenance and ensure ease of cleaning is highly important.
7. Large window sizes are preferred in order to enjoy the surrounding landscape, ensure that a large amount of daylight is admitted while being controlled in a way to assure privacy. Nevertheless, the size and position of windows to orientation is often overlooked.
8. Some developers tend to cut down the size of windows in their design because they cost a lot (FG6).
9. An architect and a project developer in FG7 stated that GRC windows are the best for use as shading devices as they come in a variety of designs and ensure privacy and style.
10. While one architect and academic supported the use of reflective glass as the best solution for windows based on real and virtual simulations, others contradicted this by noting that all types of glass are revealing at night. There is a substitute film glass that uses an electric current to change opacity but the cost of such a solution is very high.
11. The current atmosphere in Bahrain suffers from dust and, while this problem was solved in the past by the amount of palm trees available in the area, these have now disappeared, leaving space for high-rise buildings instead.
12. AC1 called for a balanced solution between modern design and cultural requirements, one that could fulfil design aspirations, have a touch of tradition yet admit enough daylight and ensure privacy.

13. A degree of '*standardisation*' is evident when it comes to fenestration in Bahrain (AC8). All windows are made with reflected glass and fixed frames.
14. Most welcomed using shading devices if their design could add a sophisticated look to the architecture's facade yet ensure privacy.
15. Architects and designers linked the loss of Mashrabiya shading to changes in the construction industry and the typology of houses after the introduction of cement. The function of Mashrabiya has changed from being useful to being a decorative device.
16. Many respondents voiced a preference for Mashrabiya but few showed concern regarding its high price although they did not know the exact price. Others wanted the material itself to be traditional wood and to feel like a real Mashrabiya.
17. '*Economic*' factors limit the chosen window treatments to a minimal level (AC6).

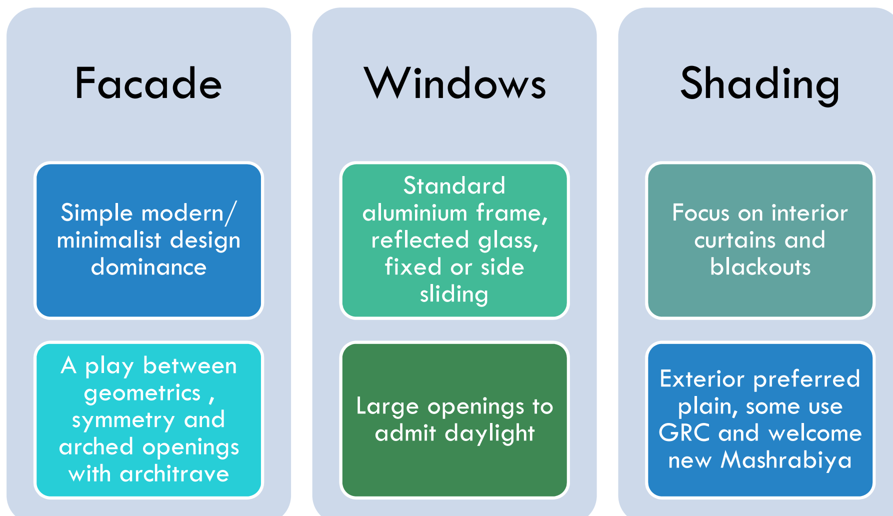


Figure 5-47 Summary of current preferences in Bahrain. Source: Author.

- **Positive and negative impressions of the 3DPM: Respondents liked it but were doubtful about it.**

  The visual impact of the 3D realistic renderings generated by the new 3DPM needed feedback from possible end users. Both the positive and negative impressions received from respondents after looking at the 3DPM visuals are analysed here. The analysis tries to aggregate the patterns of acceptance and causes for rejection.

  It is very difficult to generalise the positive and negative feedback. The members were divided into two groups, which were about equal. The positive group of about 20 out of 42 members (48%) really accepted the design and gave very positive feedback while the other 22 members (52%) showed evidence of rejecting the form or doubting its functionality in terms of privacy and environmental performance. It was also noted that the design was accepted by the majority but, since it is a new one made with uncertain material and questionable durability, they were positive about using it but with conditions. Moreover, some design adjustments were also suggested by the respondents which are explained in the next section.

Most of the first group looked at the 3DPM as an added element to the building. This might be interpreted as segregating it from the architectural design process of the building. Looking at the 3DPM as an accessory or as a focal point degrades its essential function of providing privacy. The positive group looked at it as a beautiful and sophisticated addition to the house's exterior look while those with a practical mindset acknowledged its double function of admitting daylight in an interesting way yet ensuring the privacy of the household. Respondents with an artistic eye or a background in design also distinguished the delicacy of the 3DPM in representing a 3D form of Islamic pattern that they highly appreciated. In general, an emphasis on it being a new way of veiling and an innovative, clever yet functional solution was commonly remarked upon by the first group.

The second group who rejected using 3DPM in their homes were unsatisfied by either its look or its proposed functions. In general, they were not inclined to listen to possible modifications and design possibilities that might strengthen the rate of 3DPM use. This is understandable as the power of parametrics and the customisation of any shape is fairly new in Bahrain and could not be explained clearly during the focus group session time. Form-wise, the geometric shape of the screen was found to be complex: '*felt like a jail fence*' (FG4) and '*industrial*' (FG10). The practical minds of a few men and housewives were highly concerned that the complexity of the shape would restrict cleaning; they were also wary of its price, the technology used and its durability in terms of its material and the style of its shape.

- **Customisation benefits and suggestions to improve the 3DPM:**

  Potential adjustments.

  The group who welcomed the use of 3DPM (20 out of 42 members) very much welcomed its customisation and conversion to their preferred shapes and patterns. It was even considered a '*unique*' (FG5) design tool that could add a '*personal touch*' (ARD 2) to a newly bought, ready-made house or a refurbished one.

  Looking at the current landscape and urban development, as well as families' tendencies, architect ARD2's forecast was that nuclear families would increase. Therefore, the limitations in terms of available land and house sizes might decrease, leading to the previous generation building for the next generation. 3DPM therefore might be one aspect of added personal value that could cost much less than a personal home. Although customisation comes at a price, as an FG1 member noted, a unique and specific design could be considered worth it in the long run. The benefits of this will not only enrich personal taste but also create extra competition among design professionals, as predicted by a FG2 member.

The different backgrounds, experiences and specialities of the participants engaged them in constructive discussions about 3DPM. The respondents' backgrounds ranged from marketing, engineering, information technology, quality assurance, architecture and education, etc. Different points of view were raised by supporters and opponents after the new 3DPM was shown. Many suggestions for improvements were also put forward. The following points represent an outline of what was suggested to enhance 3DPM and functionalise its use within a Bahraini residence:

1. An enhanced degree of flexibility of form in terms of adjusting shape and light control, thus allowing the window to be fully exposed or closed when needed. Moreover, the term '*foldable*' (FG5) was also suggested.
2. An ability to change the size of the 3DPM interstices according to the scale of the project.
3. A suggestion was made to combine the use of the screen with interior blackout blinds. This is just in case the openings were enlarged in a form that would make the interior exposed at night.
4. 3DPM should ensure ease of installation and long-term maintenance.
5. Patterns might be encrypted with Qur'anic verses or other calligraphy patterns.
6. Forms might be combined with indirect LED lights that can give a marvellous effect at night, or with glass art in between.
7. Sections might be cut or even perforated with narrow water pipes to allow passive cooling or window gardening.
8. An upward 45-degree angle is preferred to ensure privacy and connection to the sky.

5.3.3 The functional value theme

- **Function of Bahraini windows today**

1. The responses from most of the architects and academics show that the main function of Bahraini windows today should be to provide sufficient daylight without transferring too much heat. Also, it should ensure there is visual privacy, a view of the surroundings, ventilation during the nice breezy seasons, and add to the facade's aesthetics and decoration.
2. The windows should preferably be combined with a shading device to control the daylight penetration to a room and ensure privacy if reflected glass is not used.
3. Tinted windows and reflective glazing have become popular but are still useless at night time. When light penetrates from the inside to the outside it makes any interior activity visible. ARD 8 indicated that ordinary clear glazing, though transparent throughout the entire day, does not provide visibility during daytime due to the dark or dim lighting conditions of a residence. He also noted that it is common to find some houses with overhangs over the windows, which are only effective to some extent as the sun's angle can play a large role in solar penetration. Overhangs are static; the sun isn't.
4. Building orientation is not considered much and this has made exterior shading devices less important, as noted by AC5.
5. AC7 strongly emphasised the window design as being a crucial issue in such a hot climate. He pinpointed the importance of the window's size and location with respect to the sun's path, the ability of windows to open, shading projections and the treatments of glass panels.
6. Currently windows are enlarged in size and made of clear or reflected glass that has more of an aesthetic function than an environmental one. Thus, the heat load and energy consumption of air conditioning is ignored as a result of the size and the orientation of the windows if placed on a west or east facade.
7. Shading devices are not as popular as they were in the past. Some observations regarding the current architectural scene shows that people are trying to find new ways to avoid some opening orientations and substitute these with heavy tapestries. Some also relate the use and size of shading devices to the priority of the space behind it.
8. The Mashrabiya is considered to be one of the most thoughtful vernacular solutions to shade openings and windows, yet its dust collection, limited design options and cleaning issues restrict its use.
9. Passive cooling is not applicable during the summer period, as noted by a specialist environmental architect in Bahrain. This is due to the high amount of humidity and dust.

- **3DPM functions**

  By looking at the visual representation, possible end users who accepted the design of the new 3DPM also looked at its functional use in controlling visual privacy and admitting daylight.

  1. Through looking at the images and the shadow effect, most of the positive participants agreed that 3DPM offers privacy and ensures access to daylight. About 10% of the members, however, could not see it as functional or as allowing screening.
  2. The ability of a parametric design to change the openings of a unit in the elevation according to the daylight required and in response to the facade's orientation is better illustrated in Figure 5-48. This provide a fixable functionality of the 3D printed Mashrabiya when compared to the typical Mashrabiya.

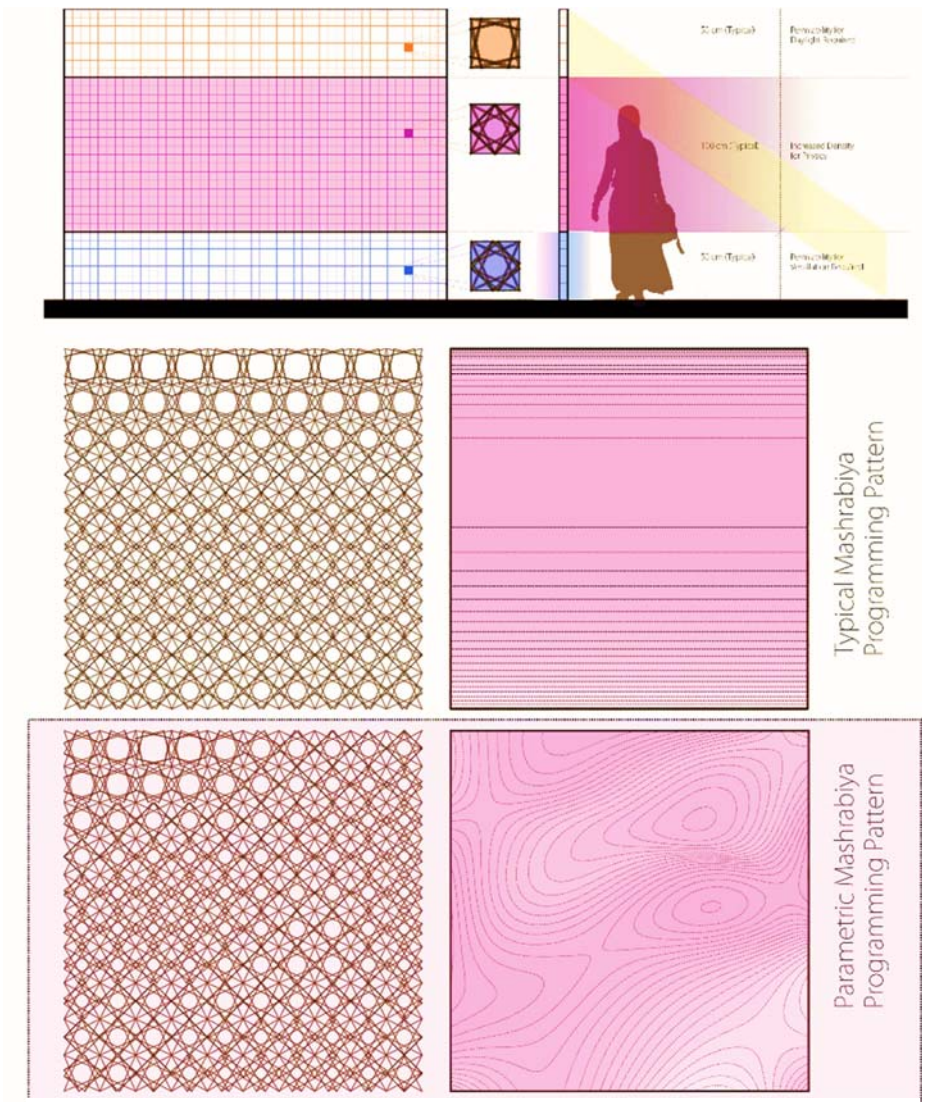


Figure 5-48 Parametric design possibilities in adjusting function of the 3DPM according to the daylight required and the facade. Source: Headley et al (2015, p. 1012).

3. The functionality of the parametrics are further explained in the co-authored article by Headley et al. (2015). In developing the 3DPM digital representation, the Grasshopper 3D plugin for Rhino allowed the screen shading diagram to be developed. The diagram derives its geometries from the traditional Mashrabiya screen. The ability to reflect traditional functionality and zoning helps in understanding the levels of daylight and privacy needed. Later, variations of the modular unit were embedded to enable the programming to be more reactive to the programmatic requirements of the interior space behind the 3DPM screen. The system is capable, therefore, of adjusting a set of given apertures and adjusting the thickness of the members to a desired transparency, as well as giving an appropriate level of ventilation.
4. Since this research experiments with the functionality aspects of large-scale 3D printing, materials and finishing behaviour have not yet been finalised. This is due to the rapid growth of technology in the field. The form presented in stage 4 using an SLS printer and nylon powder, as well as another 3D print using ABS plastics were tested against wear and humidity.

   Nevertheless, neither materials were tested nor designed for long-term wear and tear, especially in the harsh humid environment of the Middle East. The use of automobile paint was explored in 2015 by Headey et al. (2015). Taking into consideration the scale of the parts, the maintenance required for automotive paint, as well as its durability in numerous climates, can represent a potential solution. This solution might be an appropriate one for 3DPM screen scale designs that are non-performing structurally.
5. The stage 5 sand model produced in 2016 represents a new set of potentials. Due to time restrictions and the broad knowledge of environmental analysis required, daylight performance and heat transfer simulations of the model were not included in this analysis. The work of Hopkins (2014) and Karanough (2009, 2013) represent how daylight simulations of Mashrabiya-based parametric facades can be achieved and calculated and then adjusted. This relies on using the Ladybug and Honeybee plugins for Rhino and Grasshopper 3DPM definitions and codes. This work can be further investigated in future research and journal articles, or as a Master's thesis.

- **Expected functions and possible new ones**

1. The 3DPM is expected to have low thermal conductivity in order to refrain from transferring heat and glare from the exterior to the interior space.
2. Some members expected the 3DPM to be associated with south or north facades in order to help minimise the cooling load by relying on the pleasant breeze during spring months.
3. A few members would prefer the 3DPM to be more flexible so it could be openable or movable and not always fixed to the window.
4. A sense of control over daylight opacity when it enters the interior space through a 3DPM was proposed.
5. Strength in terms of security was also raised.
6. Possible new decorative applications and functions of the 3DPM in spiritual halls, like mosques, and within interior spaces to provide segregation were suggested.

- **Durability and maintenance**

1. Durability and maintenance were critical arguments raised during the focus group sessions. Both were perceived as factors to be taken into consideration during any future implementation. A member of FG1 suggested a life span of 10 years to support a purchase and another member preferred waiting for someone else to try it and approve its strength before he took the decision to have it in his home.
2. A FG2 member suggested the realistic testing of an actual 3DPM model in terms of erosion factors. Such lab experiments could forecast the advance performance within a timescale of about 10 or 20 years into the future to prove 3DPM's durability.
3. 3DPS 8, who specialised in marketing and manufacturing ExOne large-scale sand 3D printers, asserted that a sand model like 3DPM form 5 (Figure 5-49 and
4. Figure 5-50) could withstand heat and humidity if it underwent a process of infiltration. However, real environmental testing of models would provide more accurate results than virtual simulations and test his positive expectations.

Figure 5-49 Partial image of the 3DPM sand model showing the different openings. Source: Author, 2016

Figure 5-50: Sand 3DPM model; more close-up shots. Source: Author, 2016.

- **Environmental considerations and issues of sustainability**

  The pillars of sustainability are based on social, environmental and economic factors, as explained by a specialised architect in the field of energy, ARD9. Therefore, it is a significant task to understand all the factors that might influence a product's environmental and sustainable behaviour. Nevertheless, economic, social and functional values were taken as variables while material was not included in this research as it fell outside the context of the study.

  Since a final material could not be decided upon during the time in which the focus groups were conducted due to the infancy of the technology on an architectural scale, many questions were raised regarding the choice of material and if it would be an environmentally friendly one. Respondents were doubtful about the availability of current designs that balanced aesthetics with conscious environmental considerations.

  Aspiring for a material that could retain heat or reflect daylight while ensuring a lower consumption of energy inside the house was favoured by a few members of FG2 and FG4, 5 and 7.

  However, conducting trials to test a sustainable material like silica sand was perceived of as an ideal choice. Nevertheless, manufacturers of large-scale 3D-printed sand objects were hesitant to make them as a final product and not just as moulds for other mechanical parts.

Trials with 3DPM form 4 were ongoing in 2015 to print a sand part. The dilemma was to infiltrate the model and make it strong enough to undertake experimentation and transportation. Manufacturers interviewed in TCT 2015 were confident that it would be possible to print the model using new infiltration techniques. However, UK-based companies could not suggest a reliable process to infiltrate the sand model. These companies included Space Seal Technologies and Casting Technologies.

In February 2016, online communication and a follow-up with the German ExOne manager, having met at TCT 2015, led to the production of a sample sand part that was fully infiltrated and received by March 2016. The 3D printing, infiltration and shipping of a 40 by 60cm partial model occurred within a time period of one week; however, the model was received after the data collection period for this PhD study. Therefore, a reasonable decision was taken that experimentation on the real model would be included in future research.

ARD9 supported the idea that an environmentally conscious product should be produced using a holistic approach, not one that depended only on an engineer's energy calculation, although HVAC engineers have tended to find that passive cooling and Mashrabiya confuse their calculations. An understanding of the social and economics should be dealt with side by side with the environmental applications of a new 3DPM. Issues of dust, noise and insects should also be taken into consideration. The amount of light needed per space should be controlled by the Mashrabiya openings.

The issue of the sustainability of 3DPM may not only be looked at as an environmental pillar but also as a way of sustaining identity and heritage elements while representing them in a modern way. This can therefore lead to creating a holistic approach, being a catalyst example and promoting awareness, as called for in FG2 and 7.

5.3.4 The economic value theme

In order to analysis the data gathered concerning the value of economics in determining the validity of 3DPM, sub-themes relating to market scale, income and mindsets are outlined in Figure 5-51.

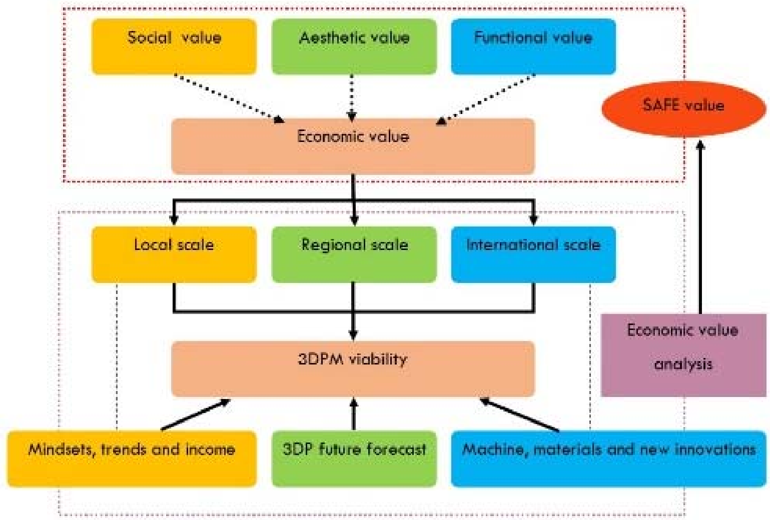


Figure 5-51 Economic value analysis with related nodes and codes. Source: Author.

- **Effects of economic factors on residential facade treatments and shading trends**

  The effect of economic factors is highly evident in respondents' answers and their choice of facade treatments. Only one opposing point was recorded by AC5, who claimed that economics does not play a major role in the Gulf compared to other developing countries who struggle to obtain decent shelters. In reality, AC9 explained that many people in Bahrain count their house as the largest investment they would make in their lifetime. People experience huge pressure in terms of loans and mortgages in order to have their dream home (AC9). Therefore, careful choices relating to materials, designs and budgets are necessary during the design and construction process. Facades and their decoration or shading are considered as a complementary issue to the essential functional elements. Many respondents aspire to obtain more elaborate designs but end up with something far less elaborate or compensate with other elements because their economic status is restricted.

  A PFG member who worked closely with residential clients on a daily basis indicated that people do not usually know where to go for the facade treatments or window shadings they aspire to have. Others do not include the shading design in their initial budget; instead, it is a later add-on which can attract a cost of about 20–25% extra than if it was planned earlier during the construction process.

The shifting concept of beauty and its value for residents also affected their decisions. If owners really like an idea or a facade element they will find a way and the money to obtain it, as a PFG member mentioned. AC3 supported this argument by asserting that '*the problem is that there are only extremes*'. Very many examples of glazing for facades are there for the sake of beauty, not function, which is extreme in a hot country like Bahrain. AC4 reasoned that such '*extreme*' and thoughtless '*examples*' were due to the low cost of energy and electricity, together with easy government rules that encourage people to disregard the economic side of a design decision in the long run.

On the other hand, AC5 stated that while people may pay for the full facade in their desired image, they might not take into account the economic cost of shading alone unless this was part of their desired image. The relatively high cost of shading, as stated by ARD7, 8 and 11, is also an influential reason for both clients and developers not using it. The economic cost of shading is therefore highly influential in both personal and development housing projects. This affects the selection of the material and techniques used, as noted by ARD3. ARD2 pointed out that there should be a moderate difference between market shading options. He asserted that clients may be willing to increase their budget by about 10–20% for better shading, yet they will certainly not go for one that is 50% extra compared to the standard.

- **Mindsets of Bahraini locals and residents**

  'Mindset' is a term that appeared while discussing social behaviour and aesthetics, as well as design decisions and cost estimations.

  1. Expats' mindsets tend to be to buy ready and functional items. They would opt for an '*Item from the shelves*' and they do not usually give lots of thinking time to their decision, as declared by a FG10 member. This is due to the fact that they see themselves living temporarily in Bahrain.
  2. For a young couple on an average income, their mindsets tend to be to look for simple elegant spaces, while they do not wish to waste money on minor aspects like shading devices or screens. An FG1 member assured buying one 3DPM shading device to use as a focal point on the facade.
  3. An average understanding and appreciation of customised products exists. The extra cost paid for customisation balances with the design's appearance in being unique and specific to the owner's needs.
  4. A cautious attitude emerged with regard to experimenting with new technology and expensive products. An FG1 member wanted to wait a while before deciding to get a 3DPM so that he would not be the first to try it and waste money on it if it proved not to be functional in the long run.

5. '*Bahrainis do not have the money*' was a common casual sentence that was repeated in FG3. Nevertheless, it represents the mindsets of many average Bahrainis who will only pay for the things they think are worth paying for. Many Bahrainis target cheaper items. This phrase also represents the low average incomes of Bahrainis when compared to the high incomes and allowances enjoyed in other GCC countries.
6. When buying or designing a new shading device, young couples tend to study the market prices before deciding if a product is worth buying or not. Capable clients may pay the average price or a little bit more but not ten times more (FG3 member).
7. A common mindset and behaviour appeared in FG3. If a product is found to be very expensive to manufacture or buy from its original supplier, a duplicate design will be requested from a local manufacturer which will be cheaper in price. The idea of replacing signature items with replicas is evident here as long as the aesthetics and functionality is achieved with a fair level of quality.
8. An underestimation of Bahrain's manufacturing market was evident during the focus groups. It was thought that it would take a long time before the prices of innovative designs like the 3DPM would drop, even if they did drop at an international level.
9. A few members admired the Mashrabiya but associated its price with expensive craft products. An experienced interior designer said that none of her clients from all social levels would pay for a shading device if it was above 850 BHD (£1573).
10. Buying branded goods is very popular yet this attitude was questioned by a FG5 member. She questioned whether people who spend all their money on brands are willing to spend the same amount on 3DPM. An answer to this was given in FG2 where it was stated that people may pay for expensive branded items but will not pay for expensive shading or veiling devices.
11. Shading devices are still looked at as a minority offering among facade treatments.
12. Mindsets in Bahrain are not willing to experiment more to prevent financial loss, especially after the economic crisis in 2008 and the inability of the government to budget adequately after the political unrest in Bahrain in 2011. ARD9 also declared that clients now feel threatened by the limited resources, the growing spaces and smaller house plots.

- **3DPM cost against the ordinary cost of a Mashrabiya**

The price of a one metre by one metre 3DPM screen was calculated earlier in section 5.2.5 to be about £1500 (850 BHD). It was important to ascertain how the possible end users would react to this cost in Bahrain. Members of the focus groups varied in their reactions, as follows:

1. The majority of participants found the price to be relatively high for the Bahraini market. 23 out of 42 participants responded to this question. 52% of them regarded the 3DPM price as very expensive while 8% doubted whether they would buy it. About 17% asserted that they might buy one or two for windows at cold points on their facades. Furthermore, only 13% of the respondents agreed that they would buy a 3DPM at its current cost while they highly appreciated its customisation characteristic.
2. While very few might pay for 3DPM at the current price for focal windows, using a 3DPM for all the windows was not realistic as this could cost a fortune.
3. If a shading screen is to be used, many would go for an ordinary GRC or CNC Mashrabiya as they would cost 50–70% less.
4. The cost of 3DPM relates to its customisation possibilities and so two of the FG1 members agreed they would pay for it if it could be customised to fit in with their preferences.
5. Price prediction was related to commerce and marketing strategies by a FG2 member. He claimed from his years of marketing experience that some products could be used to supply a targeted new market to be first sold at its cost price for about 6 months to a year until people became used to it and demanded it; profit would be made after people demanded it. The profit from this new product could not be targeted directly but gradually.
6. An elite product: FG 1 and 5 forecast that this is due to the technology being so new. FG2 member also stated that '*at this stage market segments will be constrained to higher class or established businesses*'.
7. The material determines the cost: the cost given is highly relative to the material being used for the 3DPM. Some material would repay its cost by having a longer life and so would be worth its initial cost.
8. People might not invest in buying a 3DPM until they appreciated its durability.
9. The workmanship of craftsmen is endorsed in such screens and the finishing of the new 3DPM should be worth paying for.

- **Affordable screen costs and the purchasing power of Bahraini residents**

  The average price of an affordable shading screen for Bahraini locals and residents is calculated to be about 300 BHD (£554), as seen in Figure 5-52. The responses to questions about affordable prices for screens varied a lot. The lowest price was given to a GRC screen, which can cost about 35 BHD (£64), while the maximum someone would pay for a screen is about 500BHD (£924). The 3DPM price (£1573) costs about 70% above the average affordable screen price. The prices were collected in 2015 but the 3DPM price might change according to new technologies and the material used.

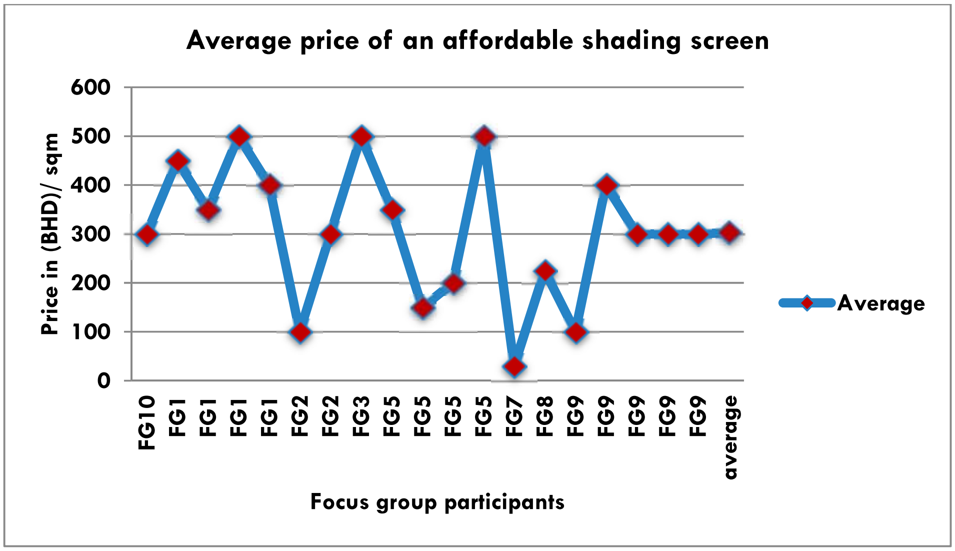


Figure 5-52: The average price of an affordable metre square screen. Source: Author.

The average price of an ordinary Mashrabiya screen, as presented earlier in section 5.2.5, is about £1557 if produced from solid teak wood using a lathe machine. By comparing the 3DPM price (£1573) to the original Mashrabiya, the difference is just 1%. However, the cost of a 3DPM (£1573) compared to an average wooden Mashrabiya that might be produced from another type of wood and technique, which can cost £1100, is about 30% higher.

Looking into the 30% from another non-profit perspective, a 3DPM can give more design and aesthetic value than a manually made Mashrabiya. This argument is further explained in a later section that compares the manufacturing capabilities of ordinary crafts against the computer skills of digital craftsmen. Further analysis is explored in Almerbati and Headley (2016) and Headley et al. (2015).

3DPS6, from a very well-known 3D-printing manufacturing company, indicated that the price of such an innovative architectural product depends on two issues: firstly, it depends on a customer who wants to pay for it and secondly it depends on coming up with a really unique and extraordinary design to balance the price.

The reality that 3DPM costs 65% above an average screen price may not make it currently an affordable solution for ordinary people. The price of 3DPM may only be afforded by elites who care about customised goods. FG6 stated that about 99% of Bahraini citizens may not be able to afford this price. Although this statement was made in a humorous way, it encompasses a fact. However, the future may shift the price of 3DPM or the economic situation in the Gulf may change and support higher incomes. Until then, it can be concluded that 3DPM is not currently an affordable shading option (2016).

An argument began among FG2 participants regarding the purchasing power of Bahrainis and its relation to consumption. Higher-class people may choose to spend their money on branded items and trendy architecture and designs. The situation might be different for middle-class and working-class people. Although the middle class would like to imitate some trends initiated by the higher class, they might not be able to imitate everything.

In general, the purchasing power of a Bahraini citizen is lower than that of other GCC citizens (FG3). This fact makes essential designs and lifestyle take priority over accessories and shading screens. Middle-class families may pay the average affordable cost of a shading screen or a reasonable percentage above it. Another participant indicated that the union of purchasing power and the willingness to buy a 3DPM might have a minimum ratio or percentage.

In many scenarios low purchasing power and conscious mindsets guide clients to choose products of moderate quality at cheaper prices. Or, clients may seek to imitate a branded design produced by other local manufacturers to get a cheaper price. An FG5 member declared that middle-class people cannot afford to put a large amount of money into exterior design or its accessories. She said that people are moving into their new empty houses with their old furniture as most of them have run out of money at this time.

- **Customisation to cost perspectives**

The fact that a 3D-printed product can be distinguished by its personalisation and customisation is a selling point. Nevertheless, the percentage of possible end users who were willing to pay extra to obtain this characteristic varied tremendously among participants. The majority of participants were willing to pay about an extra 30% or less to get customised products, as can be seen in Figure 5-53. Only two respondents were willing to pay 50% and 60% more, which represented the highest figure they would pay to get a personalised product. The average customisation percentage was calculated to be about 23% extra for an average Bahraini local or resident.

A comparison is needed between the cost of a 3DPM and its customisation percentage over an ordinary Mashrabiya (which costs 65% above average, as mentioned in the previous section), against the average customisation cost of 23%. The difference between the two is 42%. The actual increase or decrease in this percentage is highly related to market prices and innovative development. Predictions about such a market are best obtained from 3D-printing manufacturers, exhibitors and specialists in 3DP economics and manufacturing.

During the PFG session, a local manufacturing expert explained that customisation in wood manufacturing had been limited over the past years by the skills of craftsmen and due to the readily imported standard designs from international markets. In 2000, he brought the first CNC machine to Bahrain and used it to carve and customise new 2D shapes and patterns for interior and architectural spaces. Since then, CNC machines have spread and customisation preferences have increased tremendously. This is also related to new interior and architecture graduates dominating the market with new CAD skills and concepts. People in Bahrain and the Gulf region appreciate customisation more than they did 20 years ago. The spread of CNC machines has reduced the cost of customising screens as competition has raised the market standards.

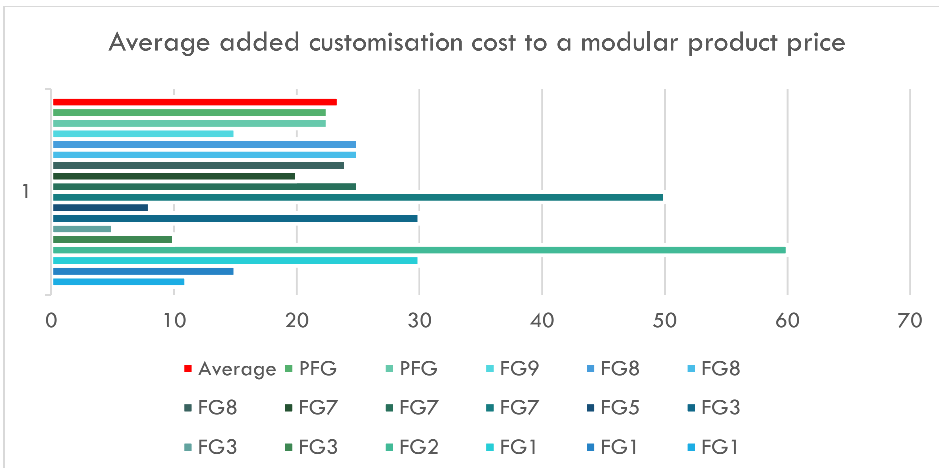


Figure 5-53: Average cost percentage of customisation to a modular product for Bahraini locals and residents. Source: Author.

Another PFG member who was a 3DP specialist joined the discussion and acknowledged the manufacturer's viewpoint. He, however, looked at customisation as a key aspect of 3D printing. He suggested that a 3DP product like the 3DPM in this research should not target the mass manufacturing market but should target mass customisation. Then, price and cost would not be an actual problem as people in the mass customisation market are willing to pay more to get what they want. This was supported by another international economist and specialist in 3D printing, 3DPS4. He asserted that 3DP mass customised manufacturing is expected to be higher than mass manufacturing as long as you can find a reason to do it this way. In the case of 3DPM, 3DPS4 pledged that it absolutely made sense to use 3DP. This application form with parametrics can be customised to fit any window size, responds positively to daylight requirements, and can be personalised with patterns and shapes.

A well-known 3DP specialist and economist (3DPS3) also supported 3DPM yet found it difficult to estimate its economic viability. The viability of the one metre by one metre screen highly depended on its shape, size and depth, and on the material powder used. There is also the printing time cost. However, a rule of thumb is that the more hollow the one metre screen is, the cost will be a fraction of the price it would be if it was a solid mass. So, if a 1m by 1m by 10cm screen cost, for example, £1000 to print, then it would cost £500 if it was 1m by 1m by 5cm in depth, or perhaps even £200 for a screen of 2cm depth, as he estimated. From the point of view of value, this could open up more business opportunities. However, for the sake of consistency and design aesthetics, the 3DPM depth here is about 10cm. His company runs special software to calculate economic models for prospective products to analyse their cost data. Unfortunately, his offer to help run an economic model for 3DPM ended after he changed his work position.

The price of the current 3DPM is expensive but this could change in a positive direction. 3DPS3 guaranteed that it would be cheaper in the future. The issue behind this is related to including the process and material for specific large-scale manufacturing companies like Voxeljet and ExOne as '*they are building significant profit margin on top of their voxel material commodity price*'. He explained also that '*the nearer you can get to the commodity source the lower the price would be*'. This statement endorses the possible lower future price of 3DPM. On the other hand, 3DPS4 suggested that if the price does not go much lower, the quality will be higher and so the printing time could be faster.

"… I have been involved in 3D printing for the past 20 years and what I can say is that we never had a set change of activity, we only had incremental changes. The set changes come when a new company comes to the market. If you draw a straight line going backwards 20 years, and if that line was based on cost and productivity and you can draw that line forward and it will be the same to me in the coming 10 years, and if it changes it's because economics will change when there is market competition." (3DPS 3)

A key fact in the constraints on 3D-printing prices are patents. The current market competition is governed by patents, according to 3DPS2. 3DPS3 supported 3DPS2 and advised that patents and intellectual property protection should be looked at as barriers that can be removed after a few years. Some leading manufacturers' technologies are patented for 20 years but once their patency expires, that market will grow. Nevertheless, the true barriers are technological, not intellectual property ones alone. For example, the FDM patent that expired in 2000 opened many innovations afterwards. 3DPS3 stated that in 2015 hundreds of thousands of FDM machines could be found in the market which reduced the price of the technology. He forecast that if MIT expired in 5 years' time, the market would see many bind jetting machines and that this would certainly benefit the end user. Other costs to consider would be that, if 3DPM was not manufactured locally, there would be transportation costs; moreover, tax, as well as fixing and labour charges, also apply.

5.4 CURRENT AND FUTURE VISTAS FOR 3DPM

While the previous section focused on analysing SAFE values relating to shading devices in general and 3DPM in particular, this section expands the analysis of 3DPM as a large-scale architecture 3D-printing product. This section relates to the local Bahraini market, as well as in regional and international markets. The aggregated reasons behind using 3DP, together with the limits of the technology, are also presented. The section also highlights future forecasts based on the primary data collected.

5.4.1 A manufacturing gap in Bahrain

The Bahraini house of 100 years ago, as explained by AC11, could not emerge without dealing with East Africa or India, or without importing material from Oman and skilled craftsmen from Basra in Iraq. There was a definite gap in the manufacturing market, which can be seen in cases such as the importing of windows from India and then designing the opening of the house, as per the design in hand. Thus, if someone was rich enough and wanted a specific Mashrabiya or balcony, he would bring a craftsman from Basra to stay in Bahrain for the time needed to complete the window design; the craftsman would then return.

The death of craft in Bahrain resulted from two factors. The first was the lack of interest from locals in undertaking hard craft jobs instead of well-paid office jobs. The second factor resulted from the lack of development and support from the government in raising awareness of the importance of crafts, and their failure to support incomes and standards. By analysing current photos of famous and average carpentry and manufacturing workshops in Bahrain, it is clear that crafts and machines are run by foreign labour. The low salaries and low educational backgrounds of foreign workers may not be helpful in developing design and form.

Although local Bahrainis and foreigners have taken architecture and interior design jobs, the influence they have on final outcomes is largely restricted to manufacturing capabilities. Most interior and architecture AutoCAD and 3ds Max renderings have to be adjusted after workshops have indicated aspects of functionality and possibilities. CR7, the owner of one of the biggest wood carpentry and manufacturing workshops in Bahrain, relies on foreign craftsmen to execute his 4 million Bahraini dinar tenders. He explained that it is difficult to find Bahrainis willing to take on such jobs that require manual skills and thought. Foreign craftsmen and labourers dominate the workshop and no women can be seen there. Long working hours to meet deadline pressures are also expected.

It is the same case in gypsum craft workshops, as noted by CR5 and CR6. Foreign labourers are headed by a master craftsman and junior labourers learn the necessary manual skills on site or inherit them from their backgrounds. Indians bring the *Jaali* making style to windows, Moroccans bring their delicate engravings, while Egyptians bring more of the turned woodwork capabilities and drawing skills. Most of these manufacturers rely on traditional patterns documented in a few books about Bahrain, or from sources of Islamic art patterns from Ottomans in French and Moroccan references, as highlighted by CR1, CR4 and CR5.

In a gypsum workshop, CR6 demonstrated how applying patterns on GFRG uses moulds and manual skills. Foreign masons used primitive skills, mostly by hand, to decorate the gypsum. However, CR6, a young son and architect, explained that using gypsum for interiors and GRC for exteriors is limited to a certain extent and eventually, maybe within a couple of years, may die out, as competition is also fierce. They do everything by hand, as he asserted:

"… we hold on to the human heritage and refrain from using any technological modern stuff."

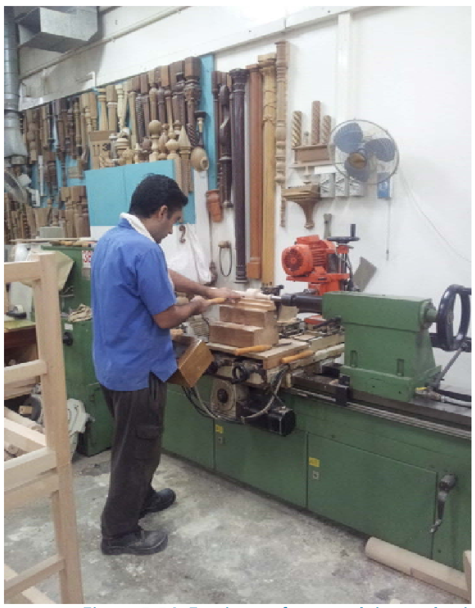



Figure 5-54: Foreign craftsmen relying on basic manual skills during CR7 workshop tour. Source: Author.

Nevertheless, these workshops and their relatively cheaper products are much appreciated by other regional countries in the Gulf. Workshops in Bahrain started doing jobs for markets in Saudi Arabia and Qatar, and for large residential homes and projects, even weddings. The new CNC revolution enabled the creation of new modern patterns using AutoCAD, Art camp and drawing tools by local Bahrainis. New modern and minimalist patterns started to appear after the introduction of CNC in 2005 into Bahrain market, as indicated by CR3.

With the influence of social media and the worldwide web, the Bahraini market started to be influenced by global design trends. Clients' demands for classical or modernised patterns could be met after 2005 using new manufacturing capabilities. Established wood workshops in Bahrain are capable of designing any sourced design and duplicating even branded furniture pieces with the use of solid wood, as acknowledged in FG3's discussion. Nevertheless, FG3 members asserted that, although they could obtain the customised design they required in these large wood workshops, this came at an extra price. However, the owners and wealthy clients of larger development projects do not mind paying for customisation as they certainly obtain durability and cut the cost of importing similar items from abroad.

The majority of architects interviewed gave assurances that the Bahraini market could manufacture most of the designs required by local projects, with the exception of specified glass. However, ARD 7, 8 and 11 disagreed about the abilities of local manufacturers. ARD8's justification referred to the lack of experience, manpower, skills and knowledge in certain forms of required craftsmanship. ARD8 pinpointed the reasons to be:

"*1) The lack of large-scale projects (especially international ones).*

2) The lack of skilled labourers. Labourers are brought from poverty-stricken countries and usually lack communication skills to comprehend what is needed. This obviously also affects how they perceive and take in any training they receive." (ARD8)

ARD7 argued that local manufacturers' capabilities are limited by the lack of advanced and developed machines. Thus, there are local limits but opportunities still exist.

5.4.2 An architectural possibility

"*…the technology is never going to push itself forward.*" (3DSP3)

3DP and architecture have been shown to be slowly developing lately compared to other industries like 3DP in the automobile or medical sectors. The reason behind its slow development is that architects are waiting for the technology to develop itself. Architects have not yet widely used the technology for their own benefits; they have not even tried to develop it. Rigorous projects have been seen remotely in the building of houses, bridges and even building blocks using 3DP. Yet, 3DPS3 asserted that 3DP will not develop unless architecture starts viewing it as more than just a tool for model making. He also indicated that 3DP is being accessed in every sector: Defence, Aerospace and Automobile and it is the sector which encourages development the most which will get the most benefits and will influence most the development of the technology. He saw Enrico Dini's D-shape machine and the Amsterdam Canal House as special 3DP architectural movements that have not yet started a revolution.

Powerful architectural revolutions start with great ideas. Known in the 3D-printing community as the man who prints houses, 3DSP12 explained his ideas and interest in architectural technology. Using his D-shape technology, architects can print impossible forms in order to approach a building as an organic space, rather than a plan of intersections. He also declared that using such technology is compelling since it does not use any cement. This is, in itself, a sustainable solution as the production of cement creates a lot of CO_2 emissions while his material relies on limestone sand and a binding agent.

In terms of 3DPM applications, 3DSP3 declared that it makes absolute sense to use 3D printing. This is because Mashrabiya attracts a very high emotional attachment, as well as social and functional attachment in the Middle East. Also, its complex geometry and aesthetics, he asserted, are key drivers to make this application the most suitable for 3D printing. 3DSP2 also confirmed that 3DP can offer design freedom that allows increased functionality. The potential for mass customisation, shortening lead-times with decentralised fabrication, provides opportunities to increase (spare-parts) supply chain efficiency, especially when opportunity costs are high. Further integration with BIM systems would allow for rapid adaptations to be made in the design which could be quickly translated into manufacturing. In support, 3DSP3 highlighted that in 3DPM design the consumer can be engaged in the design process; he/she might even illuminate the need for a designer.

The main obstacle facing 3DP in architecture in general, and in 3DPM in particular, concerns issues with scale and the durability of material (3DSP3). Although there is a growing number of large-scale 3D printers, the durability and tactility of their product are still under question. 3DPS 1 and 2 also indicated cost as another problem, while 3DSP2 indicated further limitations such as:

> *" ...Technology barriers, speed, limited process control and robustness; also lack of knowledge, standards and poor access to the technology. Moreover, the fact that there are many isolated research groups (both public and private) who are not working in collaboration. With limited knowledge sharing and synergy in research, innovation is limited. Finally, the supporting soft- and hardware is missing to create an efficient infrastructure for AM production, leading towards a mature supply chain."*

On a local scale, two of the previous problems and limitations are considered to be serious obstacles. The first is the lack of awareness between locals and manufacturers, as well as the government in Bahrain, of the possibilities of the technology. There is also a lack of educational support and software knowledge that could help design for 3DP, as noted by 3DSP1. The third limitation is the lack of predictability of 3DP materials in the Middle East's harsh winter and climate, as mentioned by 3DSP3. However, TPU 92A-1 is a material form which the leading company, *Materialize,* states is able to withstand heat and humidity, as asserted by their representative, 3DSP6, in an interview in 2014. 3DSP6 mentioned that cost, however, can be a problem, but predictions by specialists indicate a possible drop in prices. The other positive is that the Bahraini market is retainable and one or two 3DPs can satisfy the needs of the future market. This can influence savings in the transportation costs of international imported 3DP products or materials.

Reductions in other costs might be seen if locally sourced materials could be ensured.

5.4.3 Future perspectives

Internationally, most specialists and manufacturers gave an optimistic forecast for 3DP within the coming 5 years. 3DSP3 refused to give any further forecasts over a 5-year period as he claimed that many things might be developed within 5 years. Also, patents are expiring for areas such as laser sintering and FDM, 3DSP4. 3DSP2 and 6 anticipated a growth in the range and also drops in prices while 3DPS4, 7 and 9 anticipated better quality prints that were larger in size, and the availability of new materials for the same amount of money. 3DSP2 asserted that 3DP product prices would drop within 5 years' time, within 5–10 years for polymers, 10–20 years for metal and less than 5 years for plaster. 3DPS11supported 3DSP2 and anticipated a drop in the prices for architectural materials. She was also fascinated by the availability of more 3D-printed houses in the coming 5 years. This might be possible now if high-end markets were targeted, as hinted by 3DSP10, but expensive prices come with better materials or even the integration of several materials into one 3D print.

Although specialists are optimistic about the prices, they could not claim that 3DP will replace conventional manufacturing. However, 3DPS2 asserted that 3DP and AM will be an '*additional technology*' to current technologies while not replacing '*optimised, traditional*' *technologies*. This is conditional on the fact that we continue to build in the '*same fashion*' as today. With regards to architecture, he anticipated:

> *"For architecture, the advantages of traditional manufacturing (economies of scale, standardisation etc.) outweigh the benefit AM might provide for the sector. Large-scale technologies, such as for concrete printing and DMD for metals, might provide opportunities in the future, especially if the current trend of investments in AM maintains."* (3DPS2).

The need therefore exists for a new investment trend and further harnessing of 3DP capabilities in architecture to speed up the cycle of 3DP development in this sector. ARUP, a leading architecture firm, offered investments in research and 3D-printing architecture. It produced a steel structure in 2014 to create bespoke structural pieces, also optimising one. Similarly, two months later, Norman Foster's architecture firm, in collaboration with Loughborough University in the UK, announced a major investment to produce the world's first commercial concrete 3D-printing robot. See Figure 5-55 and Figure 5-56.

Regionally, rapid development projects in oil-based economies and developing countries like Doha and Dubai have made them raw markets for new innovative ideas. They have recently become involved in a race for new design concepts and manufacturing possibilities. Computation design and BIM, as noted by ARD1, work hand-in-hand with parametric modelling and 3D printing; these might be ideal for use in certain architecture projects, especially those related to reviving heritage elements and traditional vernacular solutions in modern ways.

> "*… So the market will grow, I am 100% sure of that. Within the coming 5 years we will see it everywhere*." (3DSP1, owner of the first 3DP shop in Bahrain)

Figure 5-55: ARUP 3DP steel structure. Source: Dezeen.com (2014). From http://www.dezeen.com/2014/06/11/arup-3d-printed-structural-steel-building-components/

Figure 5-56: Foster and Partners 3DP concrete structure. Source: Dezeen.com (2014). From: http://www.dezeen.com/2014/11/25/foster-partners-skanska-worlds-first-commercial-concrete-3d-printing-robot/

Locally, 3DSP1 is very optimistic about the future of 3DP in Bahrain as he has spent the past 3 years raising awareness about the technology. In 2015, he was optimistically reassuring that the future is very bright. This is because interest has just started in the education sector and this has fruitful implications. Future graduates will have more creativity and the abilities to build freeform structures supported by 3DPM. He anticipated that, since three universities had already started using it, future engineers will be part of this development cycle. The government also supports new manufacturing, as CR1 indicated, through Tamkeen, a governmental development body in Bahrain. PFG members also indicated that with 3DPM it becomes easy to design an application that can be easily customised. It might also have a local and regional reputation which will spread if materiality is enhanced with thermal functionality.

The call for the government of Bahrain to take 3D printing from the mainstream market to manufacturing was initiated by 3SP1. The motor industry around the Bahraini F1 circuit could just be the beginning of many design and product developments, including medical equipment and designs. Bahrain FabLab and all its makers could start a new small yet effective community of digital craftsmen, as acknowledged by 3DSP5 while 3DSP5 claimed that, although the technology will take time to become mature enough, others are very optimistic about it, especially since it has already been used in other well-established jewellery design fields; this will teach skills and open up possibilities that are as yet unknown but doable.

3DPS3 asked critical questions to determine if 3DP is the best technology for Mashrabiya:

> *"…So to make something that is already made using a traditional process. We look into the geometric complexity,*
>
> *Can it be used to reduce the length of the supply chain?*
>
> *Can it reduce the environmental burden?*
>
> *Can it be used to personalise the product?*
>
> *Can it be used to functionalise the product?"*

Based on all the analysis and data gathered in this chapter, and since the answers to the above questions were 'yes', a possible bright future can be anticipated.

5.5 CHAPTER CONCLUSION

The aim of this chapter was to analyse and present the primary and secondary data collected with the following objectives:

- To explore innovative ideas for reviving Mashrabiya on a local and international level through several case studies.
- To investigate metaphors and initial ideas regarding current housing design in general and 3DPM in particular.
- To measure the cost of 3DPM and large-scale 3D printing.
- To compare manual Mashrabiya making to 3D-printed Mashrabiya.
- To examine the relationships between social, aesthetic, functional and economic values in determining the validity of 3DPM.
- To forecast the validity of 3DPM in the coming 5 to 10 years locally, regionally and internationally.

The different case studies that incorporated new Mashrabiya designs, which were analysed at the beginning of the chapter, result from several interwoven values. Their architectural trends were mainly influenced by social, aesthetic, environmental and economic values that were of particular interest to this research. Therefore, these values have been coded within the interviews and focus groups to understand how they relate to 3DPM within both a Bahraini and a global context.

The local viewpoints were linked to those of international manufacturers and forecasts to assess the validity of 3DPM usage in Bahrain as an example of a Gulf region state. The analysis undertaken here supports the discussion and research argument, and tried to answer the research questions refined in Chapter 3 using the methods explained in Chapter 4. Chapter 5 compared the results gained here to other views found in the literature in order to best answer the research problem.

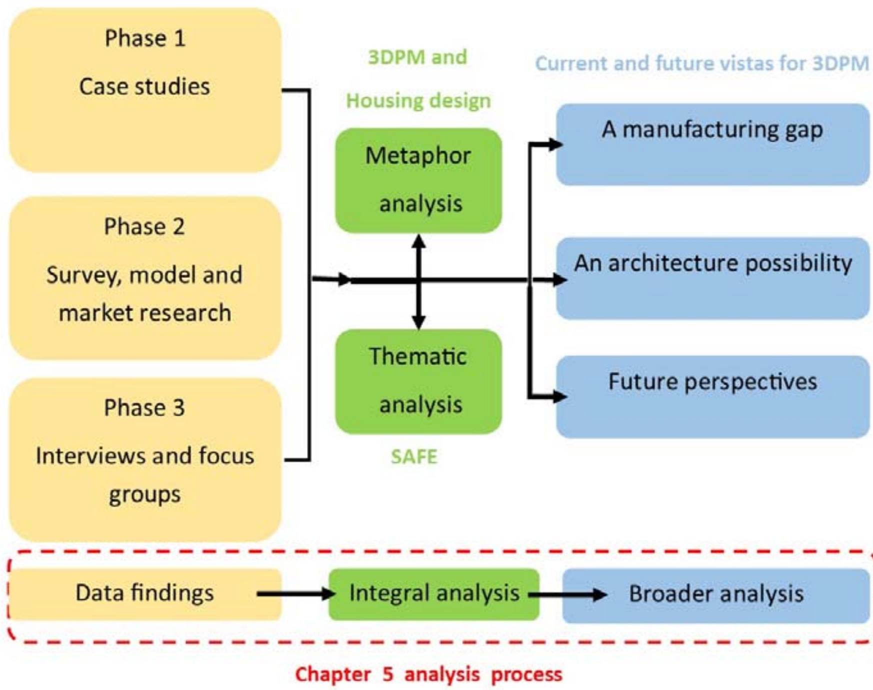


Figure 5-57: Chapter 5 analysis process. Source: Author.

As shown in Figure 5-57, through the three data finding phases, this chapter has gone into an integral analysis stage using the metaphor and thematic analysis explained in sections 5.2 and 5.3. These forms of analysis generated a better understanding of 3DPM as a product, its SAFE values and its use within housing design contexts and even as a contemporary architecture language to sustain heritage elements. A broader analysis was presented in section 5.4 to frame the findings within future manufacturing and design possibilities. The next Chapter 6 will discuss these findings and relate it to literature findings.

CHAPTER 6

"The world as we have created it is a process of our thinking. It cannot be changed without changing our thinking."

Albert Einstein

CHAPTER 6: DISCUSSION

6.1 INTRODUCTION TO RESEARCH DISCUSSION

Chapter 5 presented SAFE value data and an analysis of the current architecture and design practice in Bahrain. It also highlighted future perspectives regarding the application of 3DP in large-scale architectural production. More local, regional and international forecasts were also obtained from specialist 3D printing manufacturers. An evaluation of the practical work undertaken to develop a new 3D-printed Mashrabiya (3DPM) was presented here as well. The current chapter connects the findings from Chapter 5 to existing facts and opinions in the literature and the architectural practice documented in Chapter 2. Figure 6-1 shows how this chapter will synthesise and compare the literature and research findings derived from the secondary and primary data in order to answer the research questions first presented in Chapter 1 and refined after Chapter 3. The refined research questions are:

1. Why is the use of Mashrabiya declining in Bahraini architecture?
2. Is there a need to revive the use of Mashrabiya in Bahraini architecture?
3. What are the current manufacturing processes that are used to produce Mashrabiya and what are the associated economic implications of such processes?
4. What are the potential benefits and obstacles in adopting 3D printing techniques to produce Mashrabiya?
5. What are the values that could be used to determine the validity of 3D printing in producing Mashrabiya?

The discussion strategy adopted here is a mix of deductive and inductive reasoning in relation to the literature. The first section of the discussion answers the first three research questions and is supported by secondary data from the literature. Research questions 4 and 5 are more related to the validity of 3DPM applications, which will be discussed with reference to the aggregated findings concerning the SAFE values examined in Chapter 5.

This chapter therefore enables an in-depth understanding to be reached of the addressed research aim, together with a consideration of gaps in the literature in the field of sustaining heritage architectural elements such as the Mashrabiya. Thus, the discussion will argue that modern design and manufacturing technologies can be used as a substitute for manual craftsmen by creating new digital craftsmen. A major part of this discussion has influenced three conference papers and a journal article that link this research to several architectural production and heritage contexts (Almerbati et al., 2014; Almerbati et al., 2016; Almerbati and Headley, 2016; Headley et al., 2015) listed in Appendix A.

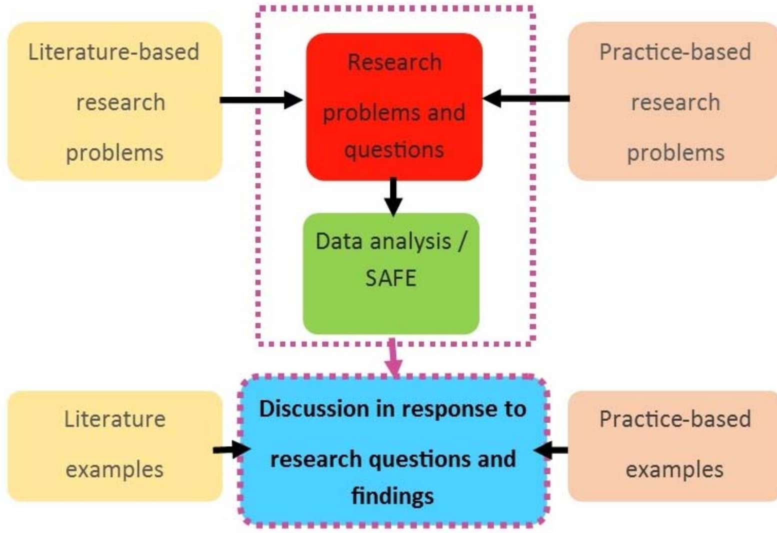


Figure 6-1 Content of the discussion chapter focusing on the research findings and supporting literature. Source: Author.

6.2 SUSTAINING HERITAGE VALUES IN MODERN ARCHITECTURE

Current architecture in the Middle East is suffering an identity crisis in the age of globalisation, as noted by several scholars (Alanazy, 2007; Dayarantne and Karajica, 2007; Dayantne, 2012). One of the reasons for this is the lack of a coherent understanding of the values associated with vernacular contexts and precedents. While Abdelsalam and Rihan (2013) urged architects to rethink the values that once elevated the vernacular architecture of the Middle East, they insisted that it was essential to nurture an appropriate regional identity. Unfortunately, the findings of the present research, through the metaphor analysis of housing design represented in section 5.3.1, support the continuation of the dilemma found in the literature between nurturing regional identity and rethinking vernacular architecture values.

The major factor behind the loss of regional identity is another problem to be taken into consideration: the unconscious 'copy-pasting' attitude seen in many architectural projects and housing designs today in the Gulf region and Bahrain. This attitude has been rejected by many scholars (Akbar, 1988; Sidawi, 2012; Aljawder, 2014). Nevertheless, focus groups conducted for the present study (consisting of professional focus group members and end users) highlighted this issue and related it to the attitudes of architects who use old patterns and architectural elements in modern designs without considering whether or not their function or material is appropriate. The survey results showed that current clients' preference for modern architecture (favoured by 33% of Focus group members) or the rising trend for a mixed style of both classic and modern (favoured by 24% plus 10% who preferred minimal modern style) means that new designs do truly lack identity.

These results, however, slightly contradict Aljawder's (2014) survey results about Bahraini style preferences. In Aljawder results, she pointed out that about 50% of her 416 respondents in Bahrain preferred a modern style while the remaining 50% preferred traditional touches on their facades, such as the use of Mashrabiya. This change in preferences over just two years can be linked to the fast development seen in modern architecture, as well as the cultural shift in style preferences and appearances. The 'culture invasion' indicated by a memebrof focus group 8 in Bahrain's Islamic society is evident in several contexts such as fashion and architecture. In section 5.4.1, the interview responses of architects and academics demonstrated that trends such as Westernisation and modernisation are influencing culture. There is also an emergence of an 'exhibitionism culture' that favours prestigious and extraordinary types of appearance, as highlighted by a few focus group members and an academics like AC9.

Nevertheless, the research gap here is not only the lack of understanding of sustainable heritage, or the overwhelming possibilities afforded by concrete; it is also the lack of catalysts or real successful examples in the landscape of current Islamic nations. The lack of viable project examples that can balance cultural and functional requirements in the Gulf region in general and in Bahrain in particular is an issue that needs to be taken into consideration. In order to envisage such leading examples in sustaining heritage image, it is evident there is an essential need to take a holistic approach to design and sustain heritage architectural elements. The holistic approach is definitely needed in order to preserve Bahrain's '*cultural legacy*', as stated by a focus group memebr, but also to respond to Eldemery's (2009) call for architects to think '*glocally*'. His term is used to acknowledge the local context of the built environment and to adhere to global design visions at the same time.

A few rare examples of consciously sustainable architecture projects and designs can be found around the Middle East. Although the concept of identity crisis cannot be generalised to all the projects seen around the Gulf region and Bahrain, a viable solution is needed. Successful projects tackling this issue were analysed by Abdelasalm and Rihan (2013), who identified three major trends: 'traditional', 'neo-traditional', and 'contemporary-oriented'. Their case study analysis of these trends took Mashrabiya-based architecture into consideration in terms of sustainable heritage architecture. Similarly, the present research examined four case studies that utilised Mashrabiya in order to not only understand the trends they were following, but to ascertain what new functionality and aesthetics were being sustained and could continue to be sustained in the new digital era. By looking into Abdelsalam and Rihan's case studies and the trends noted, it is evident that they did not tackle the appropriateness of materiality and the effectiveness of using new architectural tools in design. While Abdelsalam and Rihan's (2013) research sought to document current trends, the present research seeks to implement the 'neo-traditional' trend through using hybrid technologies to regenerate architectural facade screens which fulfil cultural obligations. This is discussed further in the following section.

6.3 MASHRABIYA AS A CULTURAL PRODUCT: FROM MANUAL TO HYBRID SOLUTIONS AND POSSIBILITIES

'*Material culturalism*', as defined by Grier (1996), is the study and research of a specific subject matter which relates the 'biosocial environment' to its contextual values. These values include religious beliefs, lifestyles, interactions, landscapes, environments and the cultural buildings of ancestors. As argued by Almerbati et al. (2016), Mashrabiya can be considered as a product that falls under the scope of 'material culturalism'. In particular, Mashrabiya is the result of many cultural and contextual environmental values in Islamic countries. Mashrabiya can be defined as a window lattice screen made from wood or gypsum. It evolved in Islamic countries in order to screen and segregate the women of a house from the eyes of outside men. Many scholars have been inspired by the richness of its historical settings; it provides visual privacy and responds to social factors, as well as to *Shariaa* (Islamic law). It also provides environmental passive cooling and even improves aspects of daylight performance, as indicated by Fathy (1986).

The manufacturing of Mashrabiya, however, relied strongly on the local craft of wood turning and carving, as well as the availability of local material. In Bahrain, the situation is different, according to what has been found from market research and interviews. Traditional Mashraiya making not only relied on imported materials but also on foreign craftsmen who were brought from Iraq or India to craft such screens, as indicated by an architecture academic (AC11). The majority of windows used local wooden louvres made from palm trees or fine wood. Only gypsum carving used to be locally crafted using limestone, primitive tools and manual skills. The result was simple screens with patterns inspired by traditional motifs or Islamic geometric shapes. This was due to the limited artistic inspiration, the high price of solid wood and its import costs. The capabilities of artisan craftsmen therefore were subject to a mixture of background skills, local materials and primitive tools.

However, things changed after the discovery of oil. The introduction of machines in carpentry shops, and lately, CNC-cut screens, changed the initial demand for such privacy screens. The demand has grown more slowly in recent years, as shown by the aspiration results from focus groups and manufacturers' interviews. This supports Aljawder's (2014) results concerning the reluctance of Bahraini locals and residents to use Mashrabiya. She calculated that 40.38% of respondents would avoid using Mashrabiya or similar traditional methods to achieve visual privacy in their homes, although visual privacy was counted in up to 58% of responses in the research survey as the top priority for window shading devices. This can be linked to users' preference for facades to look modern, as indicated earlier, and also to the lack of an aesthetically appealing shading device design option. The present research also uncovered a lack of awareness of the importance of using shading devices to reduce the environmental burden caused by large glass openings on erroneous facade orientations.

The research also concluded that there was a lack of variation and design options for Mashrabiya as a shading product. The study of Mashrabiya design as a vernacular precedent, a tool for visual privacy and an environmentally friendly solution has been coherently explained by several scholars (Kenzari and Elsheshtawy, 2003; Almurahhem, 2011; Aljawder, 2014). New approaches to its manufacturing have also been suggested by a few scholars (Abdelgelil, 2009; Bendetti et al., 2010; Samuel, 2011) and, more recently, by Karamtah et al. (2015).

Moving from research to architectural practice, several landmarks, such as the Albahar Tower, used here as a case study, are also important and valid examples. Nevertheless, most of the research and practice concerning the production of Mashrabiya screens has not collectively considered all of the possible values provided by Mashrabiya. Scholars or architects mainly considered one or two values, which were either aesthetic or functional. None of the previous work or research studies found in the literature actually produced or tackled the economics of producing such a screen, or considered its manufacturing cost or its craft industry. The Mashrabiya craftsmen are becoming more scarce and the Mashrabiya form is becoming more of a caricature without retaining its original values, as discussed by Almerbati et al. (2016) and Dritsas and Yeo (2013, p.834). In Dritsas and Yeo's article, the notion of '*Undrawable Architecture*' emerged to describe products similar to the Mashrabiya as:

> *"… Underpinned by tacit tectonic knowledge passed along generations which was never formalized, and a product of artisan craftwork of phenomenal complexity that was manually re-produced but never rationalized".*

Hence, for this screen to be reused in current architecture, it should be a drawable and valuable product yet an affordable one. For any product to be valuable and affordable, new manufacturing tools and enhanced functions should be considered if the previous ones are no longer valid or if its craft is simply extinct. Jean Novel's Arab Museum Mashrabiya and the Albahar Tower are well-known landmarks for new Mashrabiya concepts. As noted by Karanouh (2013), Albahar Tower is distinguished by its appreciation of social values and its adherence to environmental dynamics. The use of parametric modelling and weather simulation before constructing the flexible Mashrabiya made it a unique case to study. However, such a landmark must have cost a fortune to produce and only prestigious developers could afford it. In reality, this is not applicable on a wider scale in housing design projects, for example. The 3D-printed Microclimate projects proposed by Postler and Ferguson (2009), on the other hand, could be a potential way forward as they rely on parametric and 3D printing on a large scale to produce Mashrabiya-inspired pods.

Taking into consideration the spread of 3D printing technologies during the past 20 years, the conservation of this cultural screen can potentially result from the performance analysis of existing Mashrabiya. The study of existing screens carried out by Fathy (1986) and Samuels (2011), for example, can inform new parametric models, as seen in the 3DPM design stages. These were subsequently programmed into site-specific variants to be produced by large-scale 3D printers. As digital fabrication technologies continue to proliferate throughout architectural design discourse and practice (Kolarevic, 2003), the concept of a digital tectonic (Beesley and Seebohm, 2000) becomes a powerful sustaining agent in the conservation of the legacy of a historic architectural element like the Mashrabiya. This concept was absorbed and supported by the professional group members in the present study while examining the SLS partial model of the 3D-printed Mashrabiya screen (3DPM). On the other hand, in the focus group of ten possible end users regarding the approval of the revived hybrid screen model, there was both support and opposition to this model. 48% of the focus group respondents offered very positive feedback about the new 3DPM, while the remaining 52% were inclined to reject the form and doubted its functionality. It is necessary to explain that their doubt was more related to uncertainty about the materials and a lack of awareness of the capabilities of using parametric modelling for determining the functionality of the created personalised form.

The present research, however, focuses on the implications regarding tools for new digital craftsmen whose knowledge can be harnessed to program relevant design input data. Assemblies could then be generated in order to support performance from a practical vantage point, as well as informing a cultural trajectory. The idea of replacing manual labour with digital programmers or digital craftsmen emerges strongly here. Discussion about this subject was highlighted by Almerbati et al. (2016).

The aim of the present research is not to replicate a historically “frozen” Mashrabiya. On the contrary, this research contributes a holistic approach to the evolution of sustainable architecture using hybrid tools and manufacturing technologies. Its approach, and the resulting 3DPM product, tries to validate a new design tool while offering a coherent understanding of product value and identity in today’s architectural scene. Looking into the possible technology and manufacture of Mashrabiya in Bahrain, a sample case study was constructed of regional oil-based countries that share a similar economic status and design markets. An examination of several case studies and current practices, as well as understanding the technological and manufacturing barriers on a local and international scale, contributed to validating the proposed holistic approach within this research.

The new 3DPM proposed prototype for testing the holistic approach was developed according to the survey responses, in which a preference emerged for a customised geometric pattern. From the 193 responses gathered about SAFE values, the majority of respondents (54%) expressed their preference for a customised and personalised shading device for their home or flat. Geometric patterns were favoured by 49% of respondents, while 24% favoured traditional patterns. Thus, a new trajectory focusing on the design of a new geometric Islamic pattern emerged. These initial preferences led to the development of 3DPM patterns from 2D shapes to 3D and even 4D shapes that change according to time, environmental and personal preferences. Hence, the use of parametric tools and programs emerged to design the new screen model in a way that represented hybrid Islamic art but which could not be accomplished using a CNC machine. The resulting form and partial model were then analysed through the PFG and FG responses and then were synthesised with the literature outcomes. A few possible end users from the focus group members were actually capable of appreciating the new Islamic pattern generated using parametrics and found it an interesting modern and minimalist design that gave the facade a bespoke identity. While part of this research about 3DPM validity was initially a digital process, the preliminary approach was to reconcile traditional cultures with current manufacturing, regenerate new Islamic patterns and sustain values while preserving traditional architectural elements like the Mashrabiya. This research therefore sought to alleviate the current impact of industrialisation on traditional cultural artefacts and the crafts of manual artisans. In addition, SAFE 3DPM represents a catalyst or example for the architectural construction industry to enable future hybrid forms of Mashrabiya to be made.

In order to obtain a 3DPM, which was calculated to cost £1557 in Bahrain, the researcher had to pinpoint the market it could target in term of its manufacturing capabilities as advised by Ruffo, Tuck and Hague (2006). The research market analysis undertaken showed good manufacturing machine capabilities and a range of prices. Solid wood lathing can cost a maximum of £2300 per sqm as opposed to an average of £222 for CNC machine-cut screens. Yet a cheaper alternative that uses primitive tools and applications of GRC and GRG can cost an average of £111 and £68 per sqm, respectively.

The craft and production of Mashrabiyas, as asserted in the interviews with wood manufacturers and gypsum craftsmen, are reducing in popularity. This can be linked to the change in clients' style preferences, a lack of support from the government in terms of developing such crafts, or the mindsets of Bahrainis who prefer office jobs over workshop work, as indicated by CR6 and 7. Nevertheless, the government of Bahrain and its Ministry of Industry and Commerce have recently been pushing to organise more development programmes and projects to promote crafts. The 2014 report by the Bahrain Ministry of Industry and Commerce (MOIC) showed an increase of 64% in the sale of its craft gallery products (MOIC, 2014, p.24). Thus, the extra planned craft workshops and development programmes are certainly starting to show encouraging results. The industrial and business support provided by Tamkeen for start-up businesses has also spread new crafts and technologies to a great extent. Tamkeen's support ranges from 3D printing shops to wood carpentry shops, helping to equip them with advanced machines, as stated by Ahmadi (2014).

On the other hand, the education sector is playing an initial role in advancing sustainable thinking and the development of form. The outcome of the research indicates a lack of awareness of new digital parametric software packages and a lack of specific user-oriented majors like product design. In general courses, such as engineering, architecture and interior design, students should be made aware of manufacturing capabilities before entering the market, as highlighted by AC11. The education sector can provide both awareness and the tools to enable the new digital programmer or the hybrid craftsman to use parametric and 3D printing to visualise concepts, and if those concepts prove efficient they can then be taken up by the manufacturing markets to make real products and projects. In supporting non-profit organisations, like Fablab, Bahrainis may also be perceived as the missing link between makers, students in love with technology, artesan craftsmen and the general public. Therefore, the overall picture of the market shows that 3DPM applications as a mass-customised product has potential, as suggested by Cotteleer (2014) stage 4 of Figure 6-2 as Business model evolution but the values of the screen need to be discussed explicitly in the next section in order to strengthen this argument.

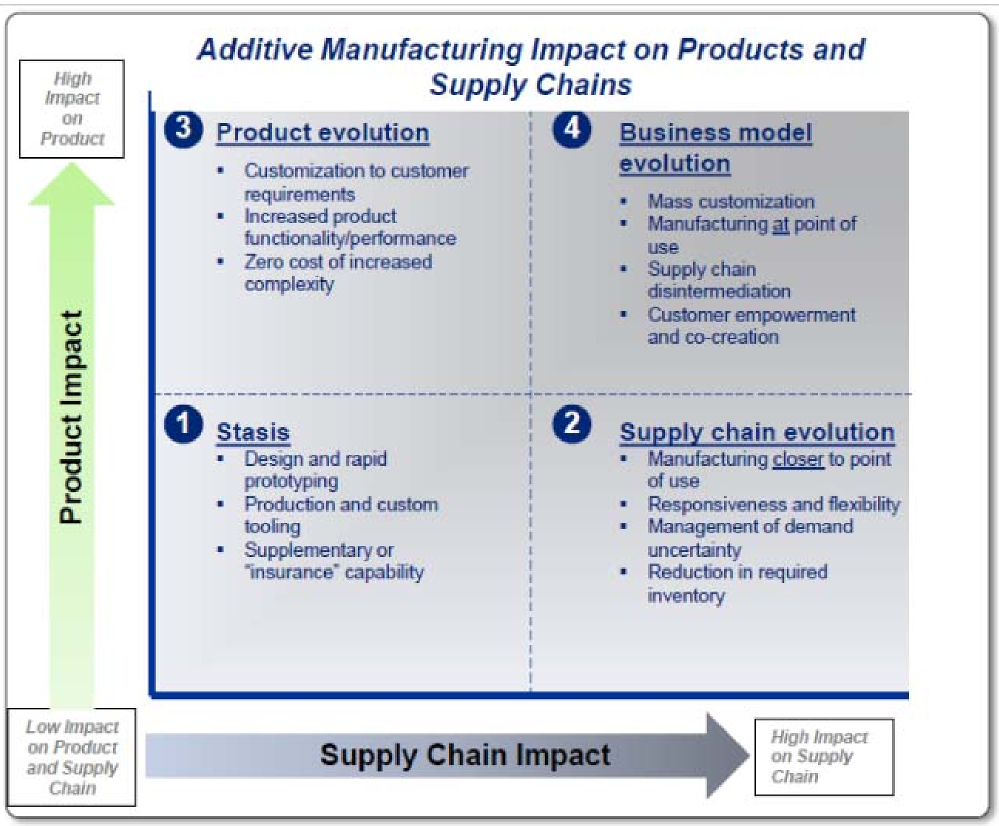


Figure 6-2 Diagram of possible 3DP market growth. Source: Cotteleer (2014).

6.4 3DPM'S SAFE VALIDITY AND THE POWER OF 3DP ARCHITECTONICS

> "*Architecture needs mechanisms that allow it to become connected to culture. It achieves this by continually capturing the forces that shape society as material to work with it. Architecture materiality is therefore a composite one, made up of visible as well as invisible forces*" (Moussavi, 2008, cited in Ko and Liotta, 2011, p.328)

Architecture does not exist in a vacuum; it is the result of several social forces and values. In order to produce a holistic product, holistic values were taken into consideration in this research project. In developing the framework for evaluating the values of 3DPM, the researcher explored both architectural and product evaluation criteria, as well as social and religious values. The SAFE (Social, Aesthetic, Functional and Economic) values were distilled in Chapter 3 and developed based on research examined within the literature review (Veryzer, 1995; Kumar, 2008; Biem & Jensen, 2011; Sidawi, 2012). In the literature, just like in any other product research, Kumar (2008) indicated several values that make a product worth paying for. Kumar (2008) derived a model he called SAFE that represents Social, Altruistic, Functional and Emotional values.

Nevertheless, these values do not all respond to products on an architectural scale, as discussed previously in Chapter 3. A new SAFE model of Social, Aesthetic, Functional and Economic values was proved to be needed nowadays. Therefore, the new SAFE model and its thematic analysis were used to validate the use of parametric modelling and 3D printing to revive the design of Mashrabiya screens. The altered SAFE model responds to various values that make it a sustainable approach in architecture. It also includes and appreciates the craft behind Mashrabiya making and the social variables it represents. Thus, it engages value-targeted parameters to define the success of a product in a Bahraini architectural context as a representative of Gulf region countries. In response to the literature review, the four values and the criteria which were designed to assess these parameters (as discussed in Headley et al., 2015, p.6) were formulated as follows:

- **Social** – Within the social and cultural setting, how does the 3DPM design work respond appropriately to the values and mindsets within an urban context?
- **Aesthetic** – How does the produced design fit into the fashion values and context of the given culture?
- **Functional** – What performative functions does the product achieve in the context of social/cultural, environmental/climatic, and emotional criteria?
- **Economic** – How feasible and sustainable is the production, transportation, assembly, and installation?

➢ **Social value found to be valid**

The social value of Mashrabiya has changed substantially. Societies utilising architecture have evolved from vernacular passively cooled settlements to modern concrete buildings with advanced HVAC systems. With the loss of labour in their construction, Mashrabiya have become caricatures of their former designs. What was previously contextualised by climate, social obligation and culture has fundamentally changed as the social character of Middle Eastern communities changed after the oil boom. However, the Islamic religion's appreciation of visual privacy is still a priority and a major concern in building and window shading solutions, as highlighted by AC4 and 5 (see section 5.4.1). When asked about prioritising SAFE values with regard to window values and their function in Bahraini homes, 58% of research respondents chose visual privacy as their main concern. This conclusion is also evident in Aljawder's (2014) survey results. In her highly significant result, 95% of respondents asserted that visual privacy was a more important matter for them than daylight. Therefore, it can be concluded that visual privacy is a driving force when choosing a window shading design and its associated functions.

Based on data gathered from the survey, and from interviews and focus groups with architects and academics, 3DPM still has a viable potential future social value. This is due to the strong Islamic religious values and the conservative nature of the community in Bahrain. Moreover, the 3DPM may functionally supplant the socially eroded versions that have resulted from the Westernisation of the architecture in Middle Eastern cultures. The programmable form can also be adjusted to serve a certain style and geometry and fit in with the '*exhibitionism and Westernisation*' phenomena of architecture in Bahrain, as highlighted by few academics and focus group members (AC4, FG2 and AC8). Hence, the new applied patterning systems represent a hybrid and stylish solution that can simultaneously re-address social concerns regarding the architectural degradation of the women's quarter in a house. This may also help, as Sidawi (2012) suggested, to prevent the identity crisis of modern houses and avoid them being perceived as '*faceless*' as highlighted by an Architecture academic (AC9).

The adoption of the new 3DPM approach to design can also promote a new regional design language to serve the '*Architecture of the veil*', as needed, and this is noted by several scholars in the literature (Kenzari and Elsheshtawy, 2003; Hampton, 2007; Ghiasvand et al., 2008; Sidawi, 2012), (see Figure 6-3).

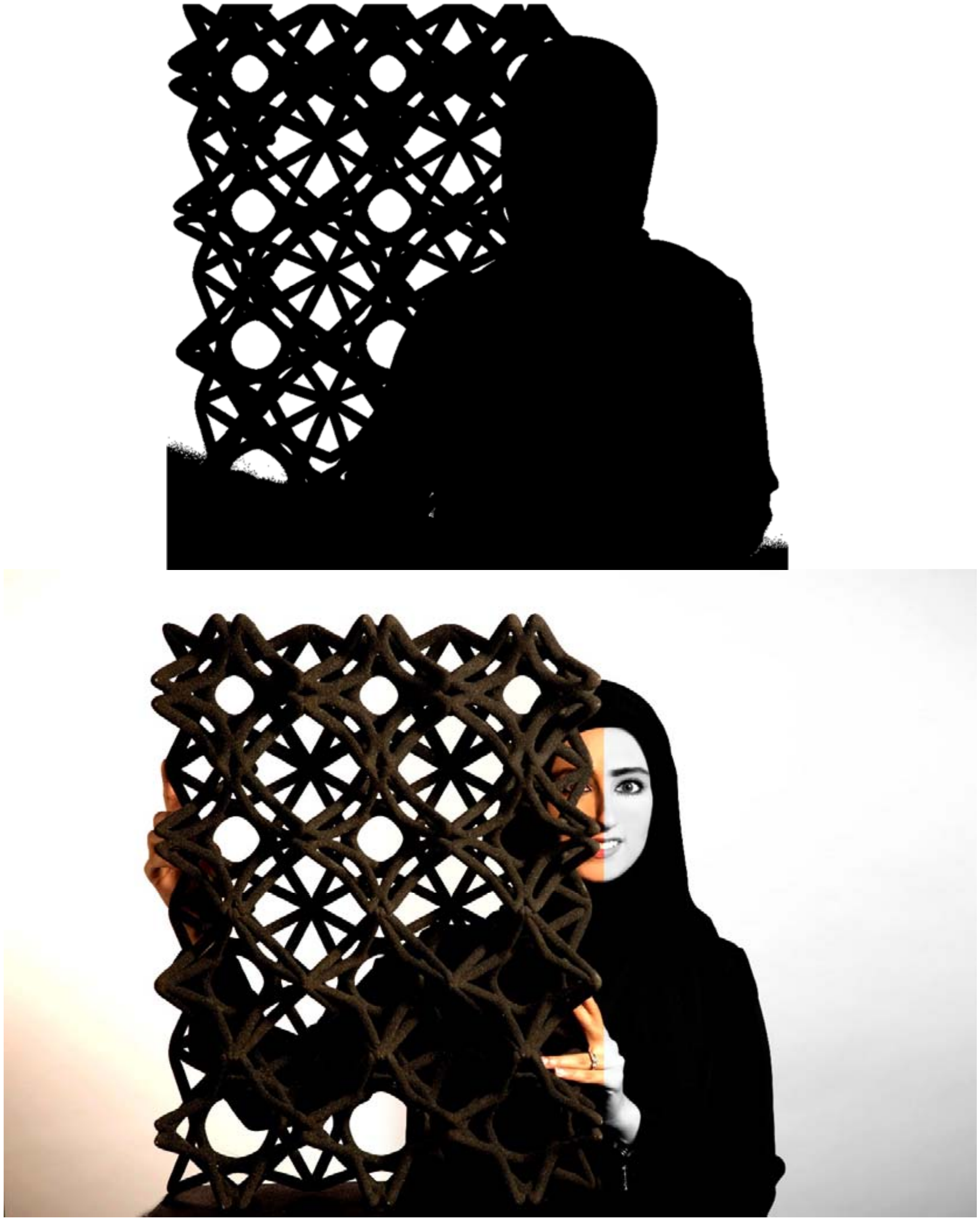


Figure 6-3 Architecture of the veil can be achieved using a 3DPM approach. Source: Author.

- **Aesthetic value has the potential to shape new 3DPM into valid forms**

The form and value of the geometry of any design is linked to the pattern creating it and to the perception of the person looking at it. The richness of the Islamic patterns and motifs that once governed the design of Mashrabiya screens has been considered as a traditional aesthetic.

Modern construction has generally rejected this complexity of ornamentation, either through cartooning or through the abandonment of shading and visual privacy screens. Mashrabiya are being substituted with abstracted Islamic patterns that are subsequently "painted" onto contemporary facades or large reflective glass openings. Some designers might use GRC moulds, as seen in the social housing projects around Bahrain. Nevertheless, modern architecture has neglected the proportions and beauty of the handcrafted screens. If those screens are used in a few projects, they tend either to be in the form of fixed shadings or decorative ones, as noted by PFG members and FG7. The research analysis has also concluded that new aesthetic standards have been imposed by social media and exposure to global trends. Consequently, the social values of '*individualism and exhibitionism*' in relation to buildings could make the mass customisation of 3DPM a welcome idea. This will be possible if designers acquire new digital skills and tools to enable them to design aesthetically appealing screens using new parametric software and 3D printing forms. This can simultaneously link architectural performance with visual impact.

The use of the skills of parametric and digital craftsmen in shaping new Mashrabiya aesthetics has been found to be of high value. This might balance the shift in the current Mashrabiya form, as claimed by Samuel (2011), from being simply decorative to being more aesthetically appealing and functional. By breaking the linearity of the 2D pattern, a more powerful dimension will appear. This linearity has been well documented in Islamic cultures such as that of Bahrain, as noted by Yarwood (1998, 2001). Likewise, in architectural practice today, this modelling technology is capable of transforming architectural facade patterns to a new level of mathematical and algorithmic formulation that is beyond the power of the human mind. Well-known projects, such as the Albahar Tower by the Aedas architects, deploy a kinetic system and an origami-inspired concept to control the passage of light. The Microclimates of the Postler and Ferguson Studio (Oborn and Chipchase, 2012) are another Grasshopper parametric example with a 3D printing output.

The complexity of the 3D form needs approval from possible end users, as well as architects and designers, in order to assess its aesthetic viability. The positive group of 20 (48%) out of the 42 focus group members readily accepted the design and gave very positive feedback while the other 22 members (52%) showed evidence of rejecting the form or its functionality because of doubts about its privacy and environmental performance. The group who welcomed the use of 3DPM also very much welcomed its customisation and conversion to their preferred shapes and patterns. It was even considered by a focus group member (FG5) as a '*unique*' design tool that could add a '*personal touch*' (ARD 2) to a newly bought, ready-made house or a refurbished one. This proves that the most influential character of 3D printing is customisation. In conclusion, mass customisation is the target market of 3DPM.

There are several trajectories for the aesthetic values of mass-customised products. While Dean (2006) put forward mass-customised pieces that could morph the parameters set by a designer, 3DPM can morph shapes according to users' contexts and preferences, and designers' interaction. The mass customisation market is expanding in both nature and quality (Wohler, 2014). These markets are expected to target high-cost products and elite end users. With reference to Conner et al. (2014), 3DP can help to eliminate the need for tooling and fixturing. Therefore, it can be more cost-effective and can reduce the amount of time before the product enters the market.

- **Functional value found to be valid in terms of visual privacy but further research is needed**

  > *"One good reason for understanding the traditional interactions between climate and buildings is that it can give guidance to how future designs might be developed to adapt to climate change."* Bougdah and Sharples (2010, p.17)

Functional values are defined by Kumar (2008) as the way a product can help achieve practical needs. Many new housing projects are ignoring basic climatic factors such as sun direction. Research interviews and field pictures show buildings that foster large-sized openings of fixed glass which rely mostly on AC systems and hardly rely at all on passive ventilation. This has created an extra amount of sunlight and heat penetrating the interior. Although exterior shading devices are of extreme importance in hot countries, they have seemed to vanish in Bahraini architecture. A 3DP Mashrabiya may provide complex geometry and aesthetics that can best provide shading for interior spaces. The fact that 3DPM can aesthetically and functionally metamorphose according to owners' needs and design desires is also an additional advantage. It can also respect the huge emotional and religious attachment to the role of privacy the Mashrabiya affords in these communities. Therefore, 3DPM could be a great architectural-scale 3DP product in the future. Strauss (2013) mentioned the need for the technologies to develop from sophisticated 3DP prototypes to reliable ones in order to have an impact on building envelopes and facades.

Moreover, the stage 5 sand models produced in early 2016 represent a new set of potentials. However, due to time restrictions and the broad knowledge of environmental analysis required, daylight performance and heat transfer simulations of the model were not included in this research as primary data. However, the work examples of Hopkins (2014) and Karanough (2013) show how daylight simulations of Mashrabiya-based parametric facades can be implemented and calculated and then adjusted according to context requirements. Roudsari et al. (2014) also supported the use of the Rhino and Grasshopper plugin to conduct such an analysis. The Ladybug and Honeybee plugins for Rhino can be connected to 3DPM Grasshopper definitions and codes to evaluate daylight performance. DIVA 2.0 is another tool that can also be used to perform daylight and thermal evaluations of Mashrabiya-based shading, as adopted by Salah et al. (2013). The Mashrabiya-based work of Salah et al. (2013) and Hopkins (2014) proves its functionality in terms of daylight control and heat reduction so the 3DPM functional analysis can be relatively proven based on the results from the literature. Further investigation of this could be the subject of future research and journal articles, or could be investigated in a Master's thesis. See Figure 6-4 and Figure 6-5.

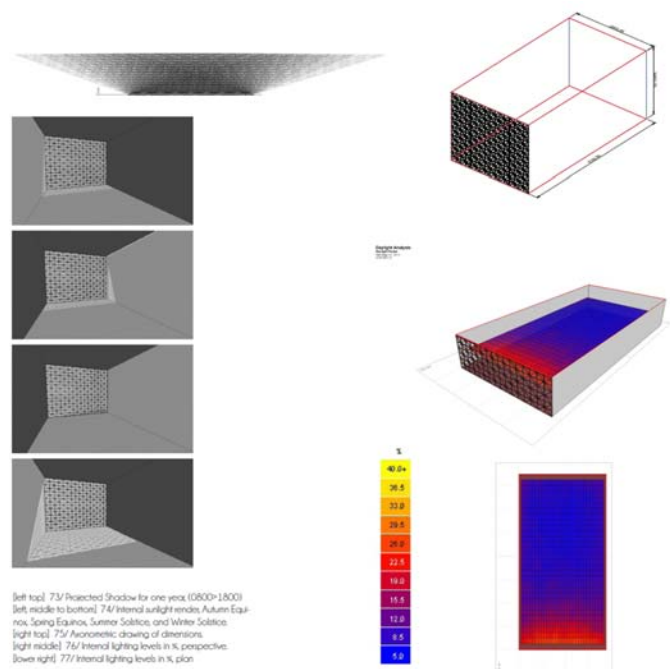


Figure 6-4 Hopkins's daylight and shadow analysis of a Mashrabiya screen. Source: Hopkins(2014, p.46)

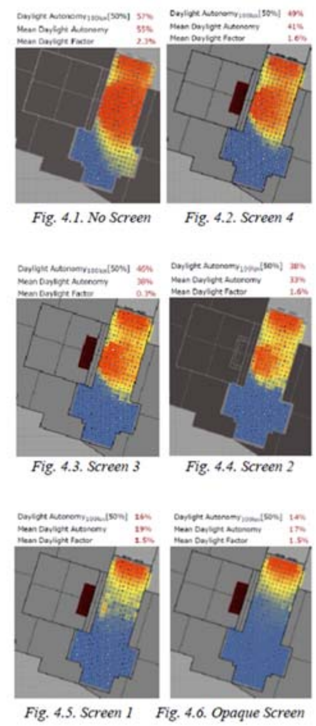


Figure 6-5 Salah et al.'s DIVA daylight analysis of different perforation Mashrabiya and IEQ. Source: Salah et al. (2013, p.6)

- **Economic value forecasted to be valid within the coming 3–5 years with conditions**

The economic validity of a 3DPM is highly dependent on its material, scale and users' mindsets, as was concluded from the analysis of the primary and secondary data collected. The effect of economic factors is highly evident in respondents' mindsets, answers and their choice of facade treatments. In reality, interviewees explained that many people in Bahrain count their house as the largest investment they would make in their lifetime. People are subject to huge pressure in terms of loans and mortgages in order to have their dream home. Therefore, careful choices in terms of materials, designs and budgets are made when they are most needed during the design and construction process. On the other hand, although people may pay the full cost for the facade to be built according to their desired image, they might not take into account the economic cost of shading alone unless this was part of their desired image. The relatively high cost of shading devices in the current market like the 3DPM is also an influential reason for both clients and developers not using these. The economic cost of shading is therefore highly influential in both personal and development housing projects. This affects the selection of the materials and the techniques used.

The average price of an affordable shading screen for Bahraini locals and residents was calculated to be about 300 BHD (£554). The lowest price was for a GRC screen, which cost about 35 BHD (£64), while the maximum someone would pay for a screen is about 500BHD (£924). The 3DPM price (£1573) costs about 65% above the average affordable screen price. The prices were collected in 2015 but the 3DPM price might change according to new technologies and the material used. The average price of an ordinary Mashrabiya screen, as presented earlier in section 5.2.5, is about £1557 if produced from solid teak wood using a lathe machine. By comparing the 3DPM price (£1573) to the original Mashrabiya, the difference is just 1%. However, compared to an average wooden Mashrabiya that might be produced using another type of wood and technique, which can cost £1100, the cost of a 3DPM (£1573) is about 30% higher. Looking into the 30% increase from a non-profit perspective, a 3DPM can give more design and aesthetic value than a manually made Mashrabiya. This argument is further explained in a later section where the manufacturing capabilities of ordinary crafts are compared against the computer skills of digital craftsmen. Further analysis is explored in Almerbati and Headley (2016) and Headley et al. (2015).

Technically, the scale and cost of materials in 3DPM production, in comparison to mass production using GRC moulds or CNC machines, is relatively high. Yet, 3DP lattice structures were evaluated in Wohler's report (2014) as reducing costs as less material is used. Conversely, the cost difference between a metre square CNC screen (£222) and a 3DPM (£1500 using a SLS or £1668 by PMMA as offered by Voxeljet), is high. Specialists would say it is still very early for architecture to be a valid substitute for mass produced elements. However, when it comes to Mashrabiya and the intensive labour and craft it requires, as opposed to the value of the design freedom of digital craftsmen, 3DP was agreed to have a benefit, as supported in the interviews with the focus group members and the specialist manufacturers. Moreover, concrete 3DP and FDM by D-shape or PMMA by Voxeljet are already well-established in this field. The experts' prediction of a lower cost in the coming five years for 3DP architecture with polymers is nearing reality perhaps, but not in metals. An alternative option suggested to produce the window screen is to use the lost-wax method; this may be economically feasible. The fact that 3DP can speed up the prototyping but not the manufacturing process of a product can add a cost for time spent versus quality achieved. More importantly, Strauss (2013) claims that by 2020 the technology will change the existing building details.

By looking into cost predictions in terms of additive manufacturing and 3D printing produced by Lim et al. (2012, p.263), it can be seen that new cost values will emerge. Experts estimate a drop in the price of injection moulding technology (see Figure 6-6). This is due to the expiration of their patents. More prices will go down in the coming five years (Berman, 2012), but not in a way that will make them 'affordable' soon. Berman (2012) also anticipated that as the prices of raw 3DP materials drop and material quality gets better, the use of 3D printing technology will expand beyond its present scope.

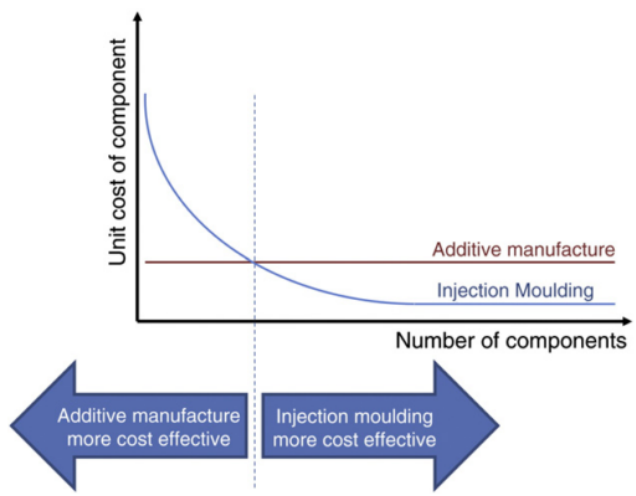


Figure 6-6 Diagram showing cost case for AM and 3DP. Source: Lim et al. (2012, p.263)

Moreover, Cotteleer (2014) and Columbus (2015) also forecasted a growth in 3D printing technology based on current market segments. They argued that 3DP and AM have the potential to amplify growth and extend their usage within the design production field. Their positive forecasts are based on the high revenue and spread of the technology after the expiration of patents like FDM in 2009 and SLS in 2014. This has a direct link to the growth of manufacturing and consumer 3DPs. Cotteleer (2014) also suggests that enhancement in the use of 3DP in production started in 2012 and is estimated to grow in 2030–2050 to create completed end products. The shift from mass-customised to purely mass-produced 3D objects will also be possible, as seen in Figure 6-7. Furthermore, Gartner (2014) projects that the 3DP market will grow globally from being worth $1.6 billion in the year 2015 to about $13.4 billion in 2018. The CAGR growth of 103.1% is definitely a positive forecast for future investments in 3DP possibilities. These possibilities can range from product development to product innovation, as is the case in 3DPM.

However, in architecture the situation is slightly different and three preliminary issues were identified by the 3DSP interviewed. The first issue is the effectiveness of the materials. Although

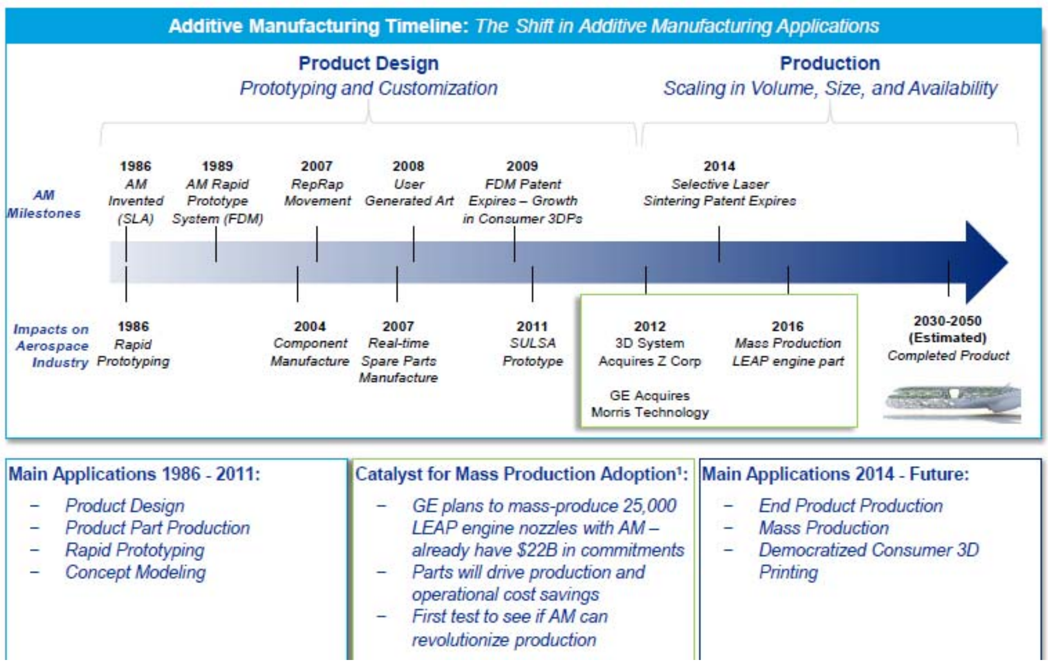


Figure 6-7 Growth forecast of 3DP during the coming years. Source: Cotteleer (2014, p.5)

there are organic materials like carbon fibre and sand, these are still being developed for exterior and interior use. The second issue is the complexity of the architectural product digital file, which is the result of complex geometry that may not always be readable by a 3D printer machine program. The third issue is the scale on which to produce these large products, which was mentioned earlier, but scholarly experiments are already being undertaken. Consequently, architecture may benefit from the increased growth of 3DP technology and possibilities only if it results in useful 3D products. Economically, these can only be viable if they are complex and it is not possible to build them using conventional tooling, or if the product printed is optimised to decrease waste in the material used. Thus, it has a long-term cost, which is its ability to decrease the 'carbon footprint', as argued by Wohler (2014). In this scenario, buildings can perhaps use 3DP products to be more sustainable yet innovative.

6.5 FUTURE MANUFACTURING SCENARIOS TO SUSTAIN HERITAGE IN THE NEW DIGITAL ERA

Culture, heritage and architecture are interwoven and shaped by the local and national history that is embedded in traditional building elements and modes. Dayaratne and Karajica (2011) and Ajaj and Pugnaloni (2014) called for a serious analysis of the rich heritage context before implementing conscious adaptations of contemporary design and technological solutions. As resources become constrained and globalisation provokes more homogenous landscapes, emerging technologies (specifically, parametric modelling, 3D printing and 3D scanning) can offer a vital solution for preserving and sustaining traditional cultural building constructs (Bohler and Marbs, 2004). Additionally, these technologies cannot only be used to understand the complexities of the original design intentions but also to suggest dimensions within which heritage archetypes can evolve (Remondino, 2011). Sustaining and reviving heritage artefacts constitutes an important challenge for contemporary craftsmen, architects, designers and specialists who seek to revive the performative capacities that inspired their original development while resisting the homogeneity generated by globalisation.

The case of TRABASA (Traditional Architecture Recorded by the means of a Building Archaeology Workshop) is an excellent example showing how old architecture, buildings and elements have been documented and analysed using 3D scanning. Mashrabiya or Roshan were key elements in this documentation and research study. However, TRABASA research was not followed by a possible implementation and use of heritage values documented for a future benefit from their study. However, the present research into SAFE 3DPM outcomes can define a valid framework for the use of 3D printing in reviving architectural screens. It can be used by cultural and local municipalities in the Gulf countries, specifically in Bahrain. This research also proves, in reference to Almerbati and Headley (2016), that documentation, restoration and replication of heritage artefacts and major architectural elements can be aided by digital preservation and manufacturing. Hybrid heritage conservation emerges when crafts meet digital fabrication. The work of Zoran (2013) is similar to the concept and aim of 3DPM since both represent the traditional with the twist of a modern frame and sustainable material.

Similarly, the nostalgia of creatively reusing an element from old traditional houses in a modern way proved acceptable to the focus group participants. Young architecture and design graduates, if equipped with the right knowledge and respect for historical monuments, can sustain heritage through their new designs. Sustaining heritage architecture and its distinguishing elements like the Mashrabiya is deeply related to cultural and social values and, once achieved, means that these elements can still be valued. The social and religious values of most Gulf cities, including Bahrain, stress the importance of privacy. Interior curtains and reflective glass windows are eminent as standard solutions for windows in houses around Bahrain. Aesthetically, as proven by Aljawder

(2014), Bahrainis are looking for creative and functional design solutions in the treatments of their exterior facades and openings.

Moreover, many heritage sites in Bahrain have been reworked to maintain old architecture with new interiors, as seen in traditional buildings like Muharraq, which was restored by the Bahrain Ministry of Culture. Such renovation projects may also adopt 3DPM for new extensions. While presently impractical for economic reasons, market analysis projects a decrease in manufacturing costs for 3D printing, enabling feasible applications of the new Mashrabiya to be devised for future housing. This prediction and usage of SAFE 3DPM responds to section 3.5 of the Bahrain 2030 economic vision for future modern buildings, enabling Bahraini architects and developers to retain a heritage influence while providing a sustainable and attractive living environment.

Figure 6-8 The contradiction of sustaining heritage within a modern architectural landscape. Source: Author.

6.6 EVALUATION OF THE PROPOSED HOLISTIC APPROACH TO SOLVE THE RESEARCH PROBLEM

By examining the values offered by SAFE, it is evident that 3D printing in architecture might not yet be applicable in enormous building projects as the printers might be of an enormous size and be difficult to control; however, smaller products like columns or screens are viable. A 3D-printed

Mashrabiya screen has been proven to offer social, aesthetic and functional benefits that may be economically viable in the coming five years. The holistic approach of looking at the social, aesthetic, functional and economic issues of 3D printing potentially enhances the suitability of the product to be 3D printed. This is of high importance when looking at architectural products that are aesthetically appealing but not functional or when simply considering the cultural concept for its potential end users.

In the post-digital age, how we design and construct has been called into question as new cultural considerations, as well as performance, are being codified. In developing the parametric models of both our culture and our construction we discover the fundamental rules at play, rules that govern the social and aesthetic constructs that we are a part of. Design and making have become liquid through ubiquitous computing and digital manufacturing. These malleable tools suggest a distillation of both construction detailing and cultural/social identity and awareness.

The constructions that have been developed (both digital and physical) explore the methods that are currently available in the light of emerging disruptive technologies. While there is evidence to suggest that these constructions can be made through other means, the adaptability of 3D printing enables mass-customised constructions to be executed regardless of siting conditions. The present research suggests that not only is the method for production a valid solution but that it also enables the crystallisation of cultural moments: the construction is a direct result of the programmed values in the design.

In response to the development of the present research, current and future parametric models and construction methods enable the production and fabrication of socially and functionally intelligent architectural products, as well as the evolution of codified systems to embody evolving cultural values. Each model provides a snapshot of the culture, as it is understood by the research: encompassing the passage of light, control of airflow, the temperature of air currents and humidity, and the privacy of the women's quarter (Harim) in courtyard houses in the Middle East. Extending this logic into future architecture might not only save archetypes, but also more clearly reveal the socio-economic, cultural and performative criteria that informed their forms.

Lastly, and perhaps most importantly, cultures do not exist in stasis and architecture does not exist in a vacuum. New questions regarding codification and construction result from inquiry into contemporary building. Building codes that were non-existent in the historic models require the parametric design to be reshaped in order to accommodate foundational architectural issues such as egress; these issues must be addressed in the new models. Design work and culture are fated to change and evolve. These new modes of design production represent an opportunity, not only to codify the products themselves into mass-customised products, but also to suggest that we might be able to reflect on both past and present cultural values and program new trajectories in social development.

There are very few references to new Mashrabiya proposals in the literature (Abdeljalil, 2006; Benedetti, 2010; Samuel, 2011; Karamata and Andersen, 2014). However the products that have been mentioned were solely reliant on the design functionality and materiality of the proposed Mashrabiya screen. The engagement of the user was missing, and also the cost was not estimated. On the contrary, SAFE requires not only a deep understanding of the socio-economic value of a new product, but offers a possibility to engage in the discussion about the designed object. This aggregated new knowledge and data relates to the end users' consumer and exhibitionism values, as addressed in Chapter 5. A documentation of such beliefs and attitudes can allow future research in the field to flourish into functional and appealing yet economically affordable designs. This results in a product that is truly processed from the end users' opinions and takes their use of the buildings into consideration as well.

The evaluation of the case of SAFE and 3DPM can be put into a balancing scale, where its individual values in terms of their future validity can be majored against t each other (see Figure 6-9. The economic burden and optimistic views on one side can be balanced by the positivity of the three other validated values (social, aesthetic and functional). The 3:1 ratio here is a realistic conclusion according to the data gathered in Chapter 5 and is supported by the literature in section 6.4.

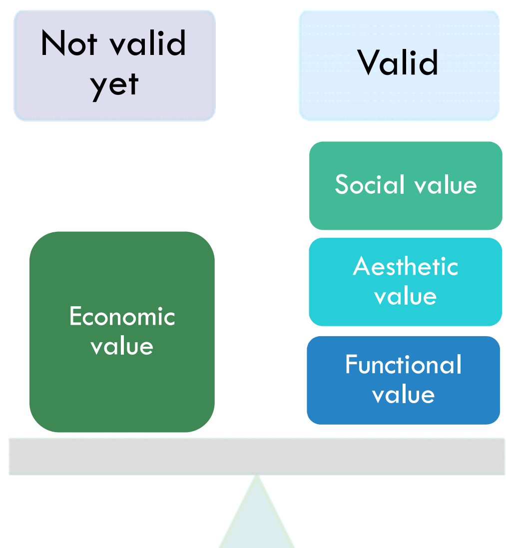


Figure 6-9 An evaluation of current SAFE validity. Source: Author.

To conclude, SAFE 3DPM can be perceived as an approach that goes beyond viewing Mashrabiya as a product of traditional architecture. It can be perceived as a holistic approach used to sustain and reproduce the architectural elements found in the Middle East to fit in with the modern context using the most recent manufacturing technology.

Figure 6-10 explains how SAFE as a holistic approach can be used to enhance the product cycle of an architectural element from research to experiment to design and manufacturing. While this model was produced for Mashrabiya, it can be generalised to other traditional architectural elements; thus, a new sustainable architecture language can be developed to best fit present users' preferences and lifestyles. This model, as with others built upon sustainable design approaches such as the work of Keoleian and Menerey (1994), Gungor and Gupta (1999), as well as Hui (2005), acknowledges environmental capital as a pivotal component in future sustainable development processes, as will be investigated in future work (see section 7.5.1).

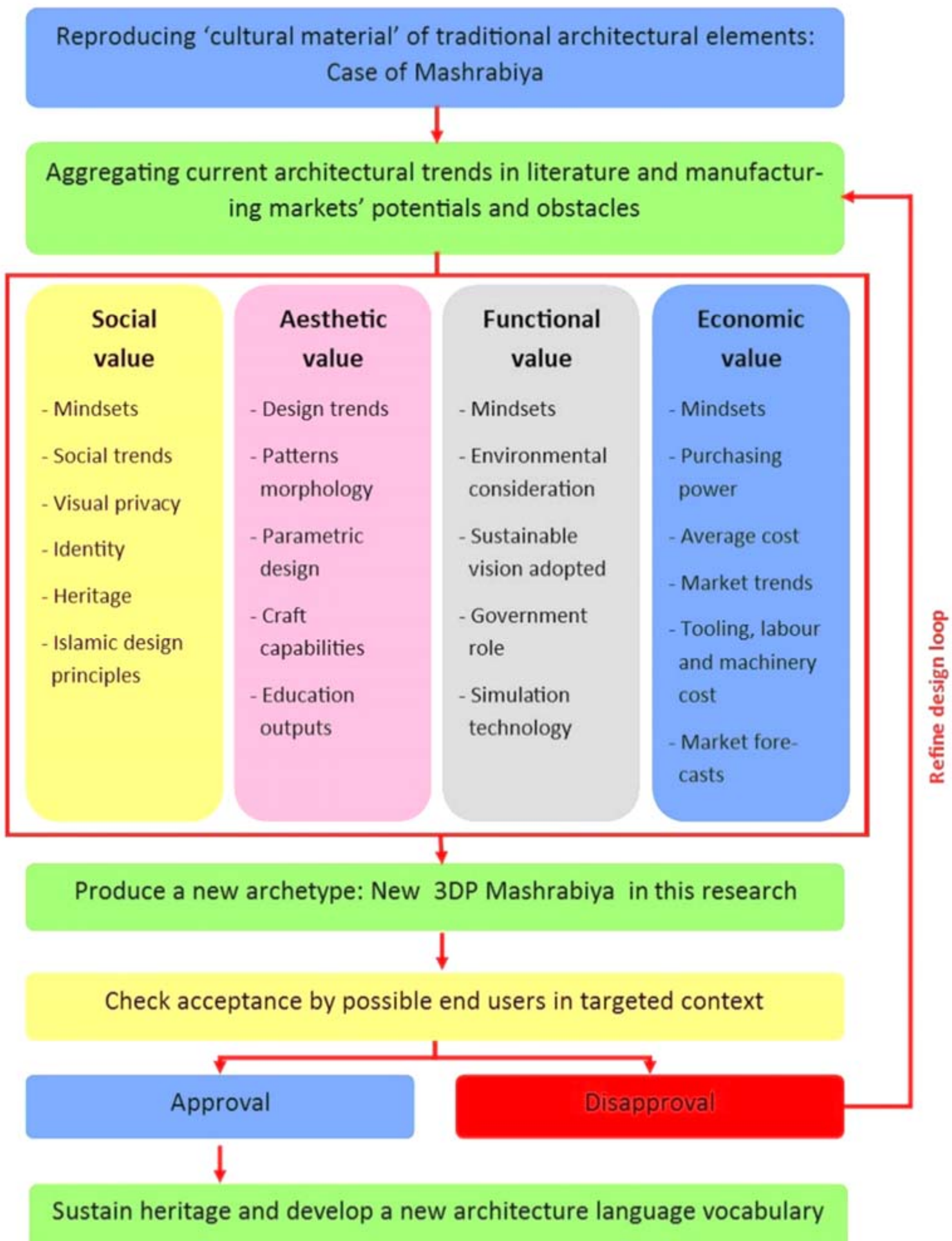


Figure 6-10 SAFE holistic approach to sustain heritage. Source: Author contribution.

6.7 CHAPTER CONCLUSION

This chapter has discussed the major outcomes of the results and findings of the present research and has linked them to other research and practices in the field of architecture and manufacturing. The underpinning literature was also highlighted. Section 6.2 looked into ways of sustaining heritage values in today's modern architecture. Then, the focus of interest, the Mashrabiya, was considered in more detail as a cultural product. After that, this chapter looked into using a framework of SAFE values to understand and sustain the heritage artefacts and architectural elements of traditional buildings. This section embraced the emergence of new digital craftsmen over the manually skilled artisan. Then, values were aggregated and analysed in terms of their effectiveness in producing a 3D-printed Mashrabiya as an example of digital craft. The research also contributes to an understanding of the implications of technologies that enable mass customisation in the field of 3D-printed architecture in general and in the Bahraini market in particular.

The benefits of using parametrics and 3D printing were further explained in sections 6.4 and 6.5. This chapter concluded by looking into SAFE as a possible new approach for adopting a new language of design elements with a cultural connection in the future. The implementations of the research findings and discussion can be interpreted in several contexts and disciplines. Further research could be carried out from this point on based on the model seen in Figure 6-10, as is discussed in the next and final chapter, Chapter 7.

CHAPTER 7

"SOCIETY and economy are changing, driven by the rise of the human creativity, which becomes a key source of competitive advantage. The rise of the ' Creative Economy' is drawing the sphere of innovation (technological creativity), business (economic creativity) and culture (artistic and cultural creativity) into one another, in more intimate and more powerful combinations than ever."

Florida (2000), cited in Collins (2010, p.19).

CHAPTER 7: RESEARCH CONCLUSION

7.1 INTRODUCTION

This chapter summarises the entire research thesis. The main aim of this research was to determine the validity of 3D manufacturing techniques in sustaining the adoption of Mashrabiya in 21st-century Bahraini houses. The aim was supported with the following objectives:

1- To gather and critically evaluate the literature about Islamic architectural values and heritage conservation in relation to the form and usage of Mashrabiya in current architecture practices, especially in GCC countries like Bahrain.
2- To establish a coherent understanding of the current manufacturing market and its techniques, as well as its economic implications, and manufacturing complications in producing Mashrabiya in Bahrain.
3- To develop a theoretical framework of a set of values that can identify and anticipate the future of 3DP and heritage architecture and assess 3D-printed Mashrabiya as a case of a hybrid heritage solution.
4- To evaluate the perception of 3D-printed Mashrabiya and its associated values as an architectural-scale product in Bahraini houses.
5- To ascertain the usefulness of the theoretical framework as a tool for sustaining the use of Mashrabiya in modern architecture.

The research aims and objectives were set to solve the research problems and questions. The SAFE framework emerged as a result of gaps in the literature and helped maintain focus on the gathered data. The refined research questions are as follows:

1- Why is the use of Mashrabiya declining in Bahraini architecture?
2- Is there a need to revive the use of Mashrabiya in Bahraini architecture?
3- What are the current manufacturing processes that are used to produce Mashrabiya and what are the associated economic implications of such processes?
4- What are the potential benefits and obstacles in adopting 3DP techniques to produce Mashrabiya?
5- What are the values that would be used to determine the validity of 3DP in producing Mashrabiya?

7.2 OUTCOMES IN RELATION TO THE AIMS OF THE RESEARCH

The research contributes to an understanding of the implications of technologies that enable mass customisation in the field of 3D-printed architecture in general and in the Bahraini market in particular. The findings and discussions articulate a hybrid heritage solution to re-interpreted Mashrabiya using 3D printing. The research outcomes are:

1. The research has collected and critically evaluated the literature concerning values in Islamic architecture in relation to the form and usage of Mashrabiya, especially in GCC countries like Bahrain. A new set of values has been defined.
2. By reviewing the current issues governing sustaining heritage and its architecture manufacturing techniques, new facts have been uncovered. The lack of skilled craftsmen and government support, and limited capabilities in the manufacturing market were pinpointed as real problems. Interviews and market data from both the local and international manufacturing markets were gathered and synthesised. CNC, GRC and GRG, for example, were taken into consideration, along with current costs and potential decay.
3. The research and literature surrounding the design values and manufacturing potentials of Mashrabiya showed a lack of understanding of the importance of the economic value and skills associated with this product. Possible new applications were examined and were proved viable. The SAFE theoretical framework was developed based on gaps in the literature and included a set of social, aesthetic, functional and economic values to produce a holistic approach to design.
4. The perception of a 3D-printed Mashrabiya and its associated values as an architectural-scale product in Bahraini houses was evaluated via a focus group of possible end users. Mindsets, purchasing powers and aesthetics were found to be major issues.
5. The usefulness of the theoretical framework was proved to be efficient in sustaining the use of Mashrabiya within 21st-century Bahraini houses through experts' feedback within published articles and conference papers. Nevertheless, the research topic and context provided an identification of further research areas were as will be discussed in 7.5.

7.3 SUMMARY OF CHAPTERS AND FINDINGS

Chapter 1 presented an overview of the entire research thesis, its background and research problems. This was followed by a summary of how the aim and objectives of the thesis would be addressed. In Chapter 2, the highlighted research problem informed the direction of the literature review. The chapter began by looking at Islamic architecture today and how it is reflected in the Arabian Gulf in general, with a focus on Bahrain as a case study. Furthermore, it examined the manufacturing market and projects that are associated with Mashrabiya as a heritage product and cultural material. The chapter also highlighted 3D printing as a possible method to use on an architectural scale. Gaps in the literature and missing values were put forward after reviewing the literature and helped to formulate the framework of this research in Chapter 3; the SAFE values were also put forward in this chapter. In Chapter 4, the methodology and the SAFE-based methods that were adopted and rejected were then explicitly explained, together with a discussion of the potential of new Mashrabiya proof of concept model development as a proof of 3D capabilities in this field.

In Chapter 5, case study, interview, focus group and market research data findings and synthesised results were analysed. Thematic and metaphor analysis were used to code the data obtained and to relate them to SAFE and architecture, as well as users' mindsets and the purchasing power of Bahraini residents and international 3DP market. On the basis of the findings presented in Chapter 5, Chapter 6 contained an in-depth discussion focusing on answering the research problem, together with a consideration of points of view put forward in the literature. An argument about the ability of modern designs being produced using 3DP manufacturing technologies was approved of in terms of its ability to substitute manual craftsmen with the creation of new digital craftsmen. Chapter 6 concluded by illustrating a design process model for developing heritage archetype using hybrid technologies like 3D printing that can be used to establish a new architecture design trend and language. To conclude the thesis, Chapter 7 summarises the research findings, its contribution to the field and recommendations, as well as noting its limitations and potential future work and practical implementations.

7.4 RESEARCH ORIGINALITY, NEW KNOWLEDGE AND OUTPUTS

Creating sustainable architecture and interiors are the targets of many architects and designers around the globe. Countries in the Middle East, like other countries, have set sustainable visions for their market, like the 2030 vision in Bahrain. However, in the Gulf region, as well as in many other countries, architecture tends to be bought "off the shelf". In reality, projects tend to copy and paste architecture and buildings from Western cultures and duplicate the images of modernity seen in developed countries. Architects and designers are not always interested in building the capacity to develop new manufacturing techniques or sustainable design language.

By looking into Abdelsalam and Rihan's case studies and the trends noted in this research, it is evident that they did not tackle the appropriateness of materiality and the effectiveness of new architectural tools in design. While Abdelsalam and Rihan's (2013) research sought to document current trends, this present research seeks to implement a SAFE 'hybrid new trend' that mediate between Abdelsalam and Rihan's 'neo-traditional' and 'contemporary' trends. This can only be holistically achieved through the use of hybrid technologies to regenerate architectural facade screens which fulfil cultural obligations.

What is being proposed in this thesis would not only be suitable in the Islamic region but would also be appropriate for other design possibilities. The strong aspect of socio-cultural sustainability associated with 3DP Mashrabiya as an example was proved valid in this research. The argument raised here is not simply about building a house to install a Mashrabiya in but is an area of investment where a person would spend a huge amount of his/her income to allow the house to function in such a way as to enhance the Muslim religion, identity, beliefs and unique social values that continue to highly value visual privacy.

This research goes beyond constructing a framework for the new production of Mashrabiya and its values. It has ambitiously validated this framework by implementing a holistic approach to design a proof of concept 3DP Mashrabiya model. This approach can be used to refine and reproduce other traditional architectural elements that can comply with the culture and economic aspiration of their users. Furthermore, SAFE can also provide a new design language enhanced by parametric CAD to customise aesthetic design solutions and make them functional at the same time.

New knowledge can also be found in the accretive nature of the present research methods where practice informs theoretical understanding of the research problem and vice versa. In detail, the methods selection and the chronological order in which these methods were used is based on the idea of design and innovation, where practice informs theory and theoretical information informs practice in an accretive process. The development of the 3DP Mashrabiya product practice is evidence of such an accretive process and is a result of action research. This research is not about producing a wonderful Mashrabiya screen via 3DP, it is about showing the potential of that technology, in order to engage reviews and feedback. Therefore, the research end result is not just a screen; the result is the feedback from the architects and end users which informed the findings of this thesis and validate SAFE. That is why there was the need to implement an initial practice and then refine it to get better results.

The testing of the model targeted aspects of its aesthetic and economic validity. The social aspect of the Mashrabiya concept, as well as the functional one, has already been proven to be valid by many other earlier researchers in the field. However, the materiality of the proposed product has not been investigated as many new innovative 3DP research materials are emerging every day. The other constraint regarding the material used is its appropriateness for the Gulf weather and for large-scale 3D printers. Therefore, this research has merely validated the framework and the approach by implementing a possible model that could be used but which needs further real-life testing. While this might be an interesting and ambitious future paper, in view of the time and funding constraints, the current PhD research could not proceed to the implementation stage of installing a real 3DP Mashrabiya on a facade for site experimentations. However, innovative materials are being improved every day. Sand is one of the latest 3DP materials that could be a possible local source for 3DP in GCC countries. The use of sand for architectural 3DP products would not only be a sustainable solution but would reduce the cost of the end product to a large extent, (Postler, 2013). Qualitative questions put to possible end users highlighted other aspects relating to the material and durability of the proposed model. A future plan to validate sand as a material could be considered after the completion of this research.

Since the framework has been validated, it can now be investigated further in terms of its sustainability indicators. Both the social and economic aspects could be combined to propose a sustainable vision for reinventing heritage architecture in an economic and socially responsive way. The SAFE framework and its design process model can create more than 'just Mashrabiya' as explained in Chapter 6'. The SAFE values could be reworked to combine the social and economic aspects into a 'sustainable' factor. An updated SAS framework could appear in the near future once large-scale 3DP material can prove its functionality as 3D-printing manufacturing technology develops. SAFE and SAS frameworks could be of high importance to other architectural products, such as the wind towers seen in GCC countries, in terms of socio-cultural and environmental values. In conclusion, the SAFE framework can be used to define a new holistic approach to reproduce other traditional elements, as discussed in Chapter 6 (see Figure 7-1).

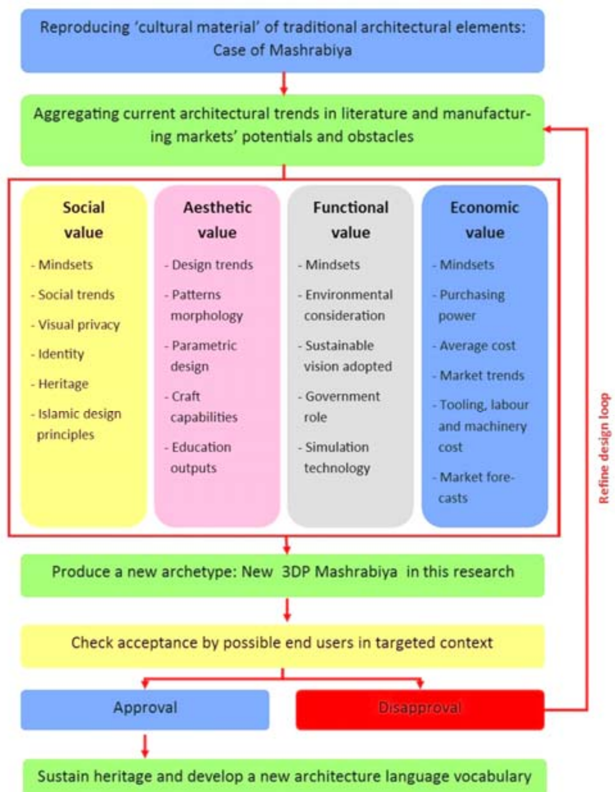


Figure 7-1Research contribution. Source: Author, see chapter 6-10.

Therefore, it can be concluded that this research has contributed to the body of knowledge within the following main contexts:

Architecture and interior design of local and regional houses:

- This research provided a better understanding of the lifestyle, manufacturing conditions and latest market research focusing on Bahrain's current and possible future development. The present findings can help houses in Bahrain to be more socially responsive; Khalifa (2011) concluded that almost all houses are not socially responsive anymore. Thus, the research has provided information on the cost and the aesthetic option of a shading device design that has not been holistically researched before in the literature. The few researchers who have proposed new Mashrabiya screens such as Abdeljelil (2006), Samuel (2011) and Karamata and Andersen (2014) did not consider local humid countries or their economic abilities.
- The research has added value to the body of knowledge on Bahrain as well as other GCC countries which share the same climate and heritage as Bahrain. As the new 3DPM can satisfy the nostalgia of having an element from old traditional houses reused creatively in a modern way in current houses.
- The study found and examined social phenomena never documented before in Bahrain, like the 'exhibitionism and 'trickledown effect' as well as design preferences that may help future interior designers and architects design for their clients in a more cohesive way.

Innovative product design and manufacturing of 3DPM:

- The 3DPM development process and adopted methods are considered as an excellent example of an accretive process of practice informing theory and theory informing practice. The methods used here can be reused by other product designers in the field of architecture or interiors. The variety of methods adopted in this research through different phases to produce the 3DPM Mashrabiya using hybrid craftsmen skills, and the input of manufacturers, architects and end users has helped make the tacit explicit in terms of approaching design in the field of sustaining architectural heritage.
- 3DPM can indeed offer an energy and daylight saving option for windows and provide a creative adjustable shape to transform to the required solar perforations and privacy level. This can make its use more sustainable.
- Until this unique research, Mashrabiya had not been researched before as an innovative product practice that is informed and highly dependent on architects' and end users' preferences. While Sidawi (2014) and Aljawder (2014) gave a documented explanation of Mashrabiya as a product of religion. Abdelsalam and Rihan (2013) looked into Mashrabiya as source of identity and trends. Others looked mostly into its functionality and passive cooling character that is not applicable in hot humid countries like Bahrain and GCC countries. 3DPM is therefore counted as a conscious application of heritage

values and hybrid technology where a balance of innovation is reached between end users' mindsets and cultural materiality requirements.

- The high cost of SAFE 3DPM proves that large-scale 3DP architecture can partly be affordable as it proves a sustainable concept. As claimed by Yousuf (2011), the initial cost of any new sustainable product may be high at the beginning but the running costs and lifecycle can compensate for this in the long run.
- 3DPM contributes to the 3D printing industry as an example of a functional product that uses digital craftsmen skills to replace the need for skilled craftsmen or foreign labour.
- The findings provide market data and references for future research and manufacturing developers in the architecture sector.

Accretive and holistic design approaches:

- The new SAFE framework can help facilitate other hybrid design solutions for reproducing sustainable heritage and its products as it can facilitate a holistic approach to design.
- Through interviews and focus group discussions, the study has helped raise awareness of 3D printing and its possibilities to users, craftsmen and local manufacturers.

7.5 OPPORTUNITIES FOR FURTHER RESEARCH

7.5.1 Environmental capital of 3D printed sand Mashrabiya

The proposed hybrid 3D printed Mashrabiya examined in the present research could benefit from further environmental simulation in order to function as an environmentally responsive design solution for use on building facades. This could support the functional and energy performance evaluation of 3D printed Mashrabiya investigated in this research. The aim of the further research is to study the impact of the visual privacy and daylighting strategies of the 3D printed parametric model on the thermal performance of an interior space. The simulation will be run using DIVA software or plugins for Rhino called Honeybee and Ladybug. This investigation can be recognised as a key component in completing the proposed SAFE framework as a holistic sustainable model. The next figures represent the preliminary results of a forthcoming journal article in Building and Environment journal. Simulation graphics are produced in collaboration with the architect Omar Elrawy, focusing on studying the environmental performance of 3D Mashrabiya in comparison to a regular plain window and an ordinary Mashrabiya (see Figure 7-3 and Figure 7-2). The article will also investigate the benefits of optimising and customising the perforations to the desired environmental needs of the context and client prior to manufacturing the screen. This is a positive point that may save costs and enhance the overall facade performance of a building.

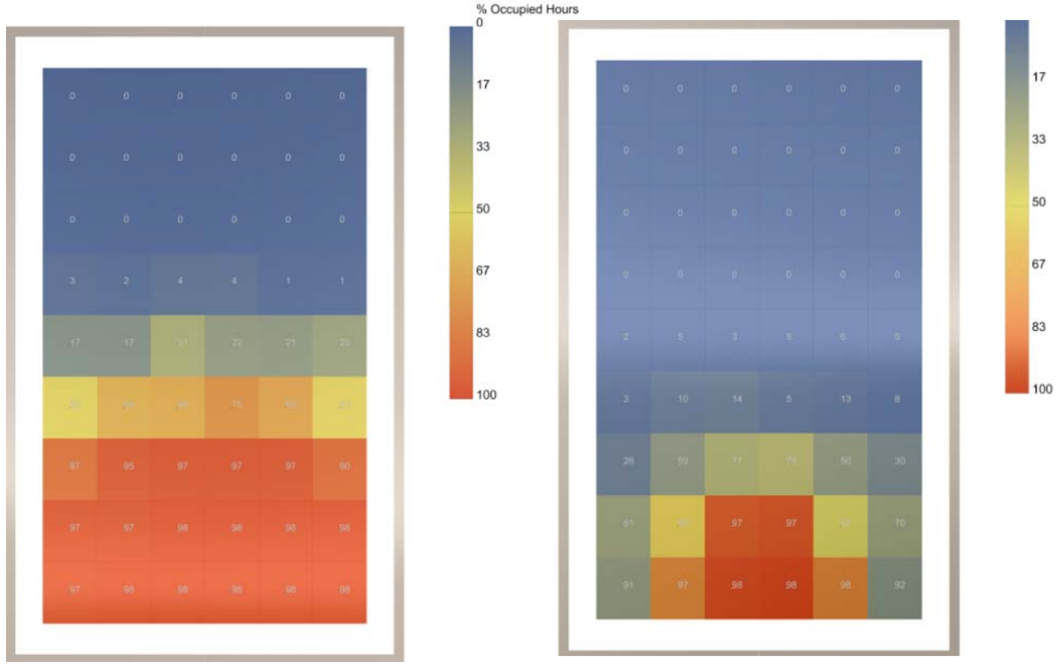


Figure 7-2 Preliminary results of a room with (right) and without (left) a 3D printed Mashrabiya using Daysim in collaboration with Omar Elrawy. The red areas of disruptive daylight is reducing when using a 3D printed Mashrabiya

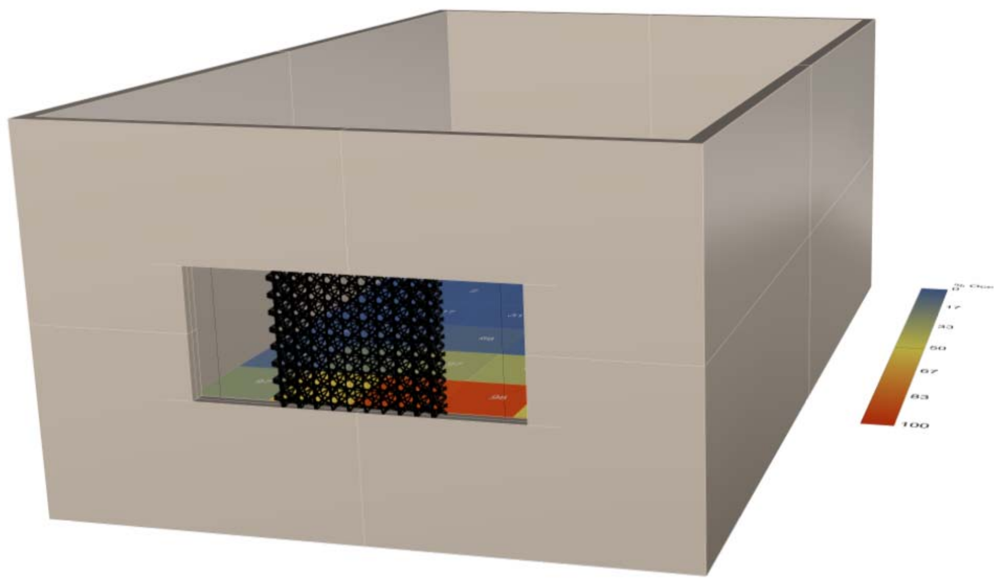


Figure 7-3 A 3D view of a 2.5 meter square 3DPM performance on a sample room. Daysim simulation in collaboration with Omar Elrawy.

7.5.2 Sustainability benefits of 3DP Mashrabiya as a post-doctorate research field

Once the framework and the SAFE values are validated, an in-depth post-doctoral research project could focus on combining the social and economic factors of Mashrabiya. Both social and economic values can be studied in relation to sustainability. Sustainability could be studied not only in the sense of sustainable materiality but also by moving further towards social and cultural sustainability. This could be achieved via its application in relation to neo-modern architectural trends. By relying on Bovea and Vidal's (2004) approach of combining three methodologies, sustainable products could be created to relate the value of the product to the customer. This could include Life Cycle Assessment (LCA), which could be used to evaluate environmental requirements. The Contingent Valuation (CV) methodology could also be used to quantify the value to customers in terms of their willingness to pay (WTP) for an eco-friendly and sustainable product.

7.5.3 Optimisation of 3DP Mashrabiya: benefits and applications

The Mashrabiya structure as a product on an architectural scale and at a high cost could benefit from an optimisation process. Optimisation studies using specialised software can emphasise the important structural geometry and reduce the use of material by considering different means of design and tessellating components. This could lead to a tremendous reduction in manufacturing costs. The gains also include creating a lightweight structure which could be more functional or could incorporate new thermal functions alongside the approved aesthetic geometric function.

7.5.4 GCC consumer behaviour concerning 'customisation' and 'individualisation'

The GCC countries attract global markets as they consume high-end brands and expensive products. New social trends found in the present research like 'exhibitionism' promote the need within GCC communities for individuals to achieve 'social distinction'. Both product customisation and individualisation can therefore be of high importance in these markets. The 3D printing distinctive character of customisation can be studied as a new market for crafts, art and individualised designed objects.

7.6 RECOMMENDATIONS

Recommendations to enhance the current architecture and craft scene are summarised as follows and addressed to the main bodies that control the Bahraini society's socio-economic development locally and regionally.

A. Bahraini local governmental bodies:

- The Ministry of Housing and government municipalities should encourage sustainable movements and solutions, not only in terms of the energy conservation of proposed designs but in adhering design to local style and cultural obligations.
- SAFE can be used on a local or international level as a guide for architects, designers and municipalities in the reproduction of other heritage-based architectural element in modern projects.
- Government bodies such as Tamkeen and the EDB should understand, encourage and develop the basic skills needed to start a new '*Maker Movement*' in Bahrain. It is these bodies which can take the technology beyond its current limits, as business profits are not always the Makers' target.
- The Ministry of Industry should look into new manufacturing possibilities and encourage new potential technologies such as 3D printing.
- The Ministry of Industry should prioritise development programmes and workshops that sustain local crafts. It should support these financially and source a decent income for their practitioners.
- A collective manual of the capabilities of the current architecture manufacturing market and current prices should be produced and updated every five years to map developments and to spot market growth and obstacles to be addressed by the government. A projected forecast of these developments and its related economies should be regularly analysed.
- Sustaining heritage and reproducing it in a modern way could be a trend that can be adopted by the Ministry of Culture in Bahrain. This could raise awareness and establish new architectural and interior design concepts to frame the future development of a 'glocal' architectural language in Bahrain and the Gulf region.

B. Education system:

- The education system, led by engineering and architecture as well as interior design courses, should integrate special courses on manufacturing and product production into the curriculum. This could increase awareness of production instead of the focus being on importing foreign goods and skills to the market. Parametric modelling should be appreciated and integrated as well.
- Awareness of traditional architectural values and its related socio-economic importance could be taught to children from a young age in both private and governmental schools.

C. Private sector:

- New development projects by the private sector may be assessed to ensure the adaptability of the proposed design to local social and economic needs. Thus, these projects can articulate SAFE within their design concepts.

D. Media:

- Awareness of traditional crafts as well as innovative manufacturing technologies could be appraised by local media tools and programs. In addition, the power of social media can be utilised in this context.

E. Regional governments:

- Regional governments should support and seek contemporary interpretations and formulations of Islamic architectural vocabulary and syntax, which could take into consideration historical, social, cultural and current lifestyle needs.
- Regional governments should encourage new hybrid development approaches based on traditional approaches. Thus, this would involve learning from the past to deal with contextual weather extremes and adapting future designs to enable better performing buildings, which are at the same time aesthetically appealing.

7.7 LIMITATIONS

- The lack of literature regarding manufacturing and the production market in Bahrain was an obstacle.
- The research context was limited to the Bahraini market and residents and the subject of Mashrabiya and its values.
- Some key professionals and manufacturers could not be interviewed due to clashes in available meeting times for interviews and site visits.
- Most focus groups were conducted online as it was difficult to arrange common meeting times among all the participants.
- Some manufacturing companies declined to allow access to their manufacturing workshop.
- The researcher has no way of estimating an accurate build cost for Mashrabiya as many factors, such as size and material, as well as fixing cost, could be different to the cost given by individual manufacturers.
- The duration of the PhD research programme did not allow other aspects to be covered that might have provided a better understanding of the subject area, like environmental simulations analysis which will be carried on postdoctoral research.

- Constraints in terms of a lack of financial resources and time limited the production of a full-scale product to test its functionality and durability.

7.8 CONCLUDING COMMENTS

Although extensive research has been carried out on Bahrain's traditional and modern architecture, no single study has shown the effect of socio-economic factors on architectural products in the 21st century in Bahrain. The work of Yarwood (1988), Fuccaro (2001), Elmesri (2010), Ben-Hamouch (2004), Dayaratne and Karajica (2012) and Aljawder (2014) are examples focusing on both social or architectural factors and urban development in Bahrain. In response to the knowledge gap in the literature, this research can be considered as contributing a better understanding of lifestyles, manufacturing and market research.

Research into the creative industries, especially architecture and manufacturing, is highly necessary as both are important contributors to the country's economy (Collins, 2010). The merits of the new holistic SAFE value approach used in this research if combined with awarness to enviromentaly responsive design and sustainability principles can contribute to a better understanding of design and production. The approach integrates and interacts with past and current factors that influence architecture and product design in Bahrain, making it possible to be adopted by future designers and architects in response to their call for change in the design strategy and vocabulary, as outlined earlier in Chapter 1 and 2. Moreover, the conclusions and data gathered can help both policymakers and industry professionals to share reliable ideas, communicate key concepts and make a valid case for key investments.

On an economic level, the impact of new digital tools, as well as collaboration and outsourcing relationships within the creative industries in the world and in Bahrain as an example, is evident in this research. The new modelling, design and manufacturing tools tested here offer raw new knowledge that is in need of research and understanding as new markets emerge every day in the new digital age. Social and physical needs and services should be reflected upon regularly in order to cope with the technologies imported to Muslim countries in order to make them fit in with their cultural and environmental needs.

The research presented articulates a design process that seeks to develop a contextual understanding and develop a digital tectonic for Mashrabiya design. This work is still in its preliminary phases in terms of the exploration of culture, the parametric model development and the examination of making processes. The frameworks of the material culturist, digital tectonic and digital craftsman suggest a sequential methodology that enables the parameterisation of cultural values into a model that enables the continued growth of both architectural archetypes and culture.

The parametric Mashrabiya, as it continues to evolve through recursive analysis of cultural material within various Eastern cultures, will continue to gain design intelligence. Simultaneously, the embedding of these intelligences does not preclude each of the features' continued intensification or termination, enabling cultural evolution/revolution. Furthermore, the parametric model also enables the articulation of detailing that is adaptive to the required spatial constraints, daylighting and performative needs that extend beyond the outlined cultural criterion, enabling these new forms to continue the evolution of the tradition. The merits of the proposed design maintain the precepts of Shari'a (Islamic) law for private dwellings while improving lighting through the upper and wider latticework. Although privacy considerations are no longer strictly followed in modern building codes in the Middle East, the proposed parametric design treats the upper latticework in a way that harmonises social and environmental needs.

Finally, the parametric Mashrabiya enables the digital craftsman to produce a new customised construction using new manufacturing methods for a traditional craft. While 3D printing of the Mashrabiya might be equal to or greater than the present cost of fabrication when taking into account longevity and scale, it is not unreasonable to assume that as technologies continue to evolve, this cost will decrease while the lack of artisans is likely only to intensify, subsequently increasing the cost of construction.

In conclusion, societies and economies are changing due to the rise of human creativity, allowing many opportunities for competitive design advantages, as noted by Florida (2000), cited in Collins (2010, p.19). The cycle of innovation is therefore driven by the 'Creative economy' that is highly influenced by new technologies. Nevertheless, as opposed to aspects other than aesthetics and function, the economic validity of a new product must fit within social contexts which are constantly changing.

BIBLIOGRAPHY

ABDELSALAM, T. and RIHAN, G. (2013) The Impact Of Sustainability Trends On Housing Design Identity Of Arab Cities, Housing And Building National Research Center*, HBRC Journal,* 9, pp.159-172.

ABDELGELIL, N. (2006) A New Mashrabiyya For Contemporary Cairo: Integrating Traditional Latticework From Islamic And Japanese Cultures. *Journal of Asian Architecture and Building Engineering*, *5*(1), 37-44.

ABULFATEH, A. (1987) (translation), *Bahrain Old Houses*, photographs by: AL-KHAN, A., Falcon Cinefoto and Gulf Panorama Publishing.

AHMADI, N. (2014) Digital Fabrication in Architecture: A Feasibility study for its Application in Bahrain (Fab Lab). Unpublished thesis (Master of Engineering Management), The George Washington University.

AJAJ, A. and PUGNALONI, F. (2014). Re-Thinking Traditional Arab Architecture: A Traditional Approach to Contemporary Living. *International Journal of Engineering and Technology*, *6*(4), pp.286-289.

AKBAR, J. (1984) *Responsibility and the Traditional Muslim Built Environment*. Unpublished thesis (PhD.), Massachusetts Institute of Technology.

AKBAR, S. (1994) The Diminishing Role of Windows from Traditional to Modern: The Case of Jeddah, Saudi Arabia, *Role of windows in Saudi Arabia*, 1994, p. 16-21.

AKBAR, S. (1998) *Home and Furniture: Use of Meaning of Domestic Space, Jeddah, Saudi Arabia*. Unpublished thesis (PhD.), Newcastle University.

AKBAR, J. (2005). *Imarat Al-'Arth fe Al-Islam (Architecture of Land in Islam)* (4th ed.). Beirut, Lebanon: Alresalah Publishers.

AJIBOLA, K. (1997) Ventilation of spaces in a warm, humid climate: Case study of some housing types, *Renewable Energy*, 10 (1), pp. 61-70

ALAALI, M. (2006) *A house in Bahrain*. Unpublished thesis (MArch.), Virginia Polytechnic and State University.

ALALI, N. (2000) Veil (Book Review). *Journal Of The Royal Anthropological Institute*, 6 (3), pp. 543-545, Academic Search Premier, EBSCOhost, viewed 28 March 2015.

ALDAWOUD, A. (2013) Conventional Fixed Shading Devices In Comparison To an Electrochromic Glazing System in Hot, Dry Climate. *Energy and Buildings*, 59(0), pp. 104-110.

ALENAZY, T. (2007) *The privacy and social needs of women in contemporary Kuwaiti home*. Unpublished thesis (MA.), Florida State University.

AL HUSSAYEN, M. (1995) Significant characteristics and design considerations of the courtyard house. *Journal of Architectural and Planning Research*. 12, pp. 91- 103.

ALI, J. (2008) Bahraini's vision until 2030: a new paradigm. *Gulf News*. 1st Nov. Available from: http://gulfnews.com/business/analysis/bahrain-s-vision-until-2030-a-new-paradigm-1.141550. [Accessed 22/3/2016].

ALJAWDER, H. (2014) *Residential windows daylight vs. visual privacy*. Unpublished thesis (PhD.), University of Sydney.

ALJOFI, E. (2005) The potentiality of reflected sunlight through Rawshan screens. In: *Proceedings from the International Conference of Passive and Low Energy Cooling for the Built Environment* May 2005, Santorini, Greece

ALKHALIFA, F. (2015) *Urban sustainability and transforming culture in the Arabian gulf: Case of Bahrain*. Unpublished thesis (PhD.), University of Sheffield.

ALNASER, W. and ALNASER, N. (2011) The Status Of Renewable Energy In The GCC Countries. *Renewable and Sustainable Energy Reviews*, 15(6), pp. 3074-3098.

ALMERBATI, N., FORD, P., TAKI, A., DEAN, L. (2014) From Vernacular to personalised and sustainable: The value of additively manufactured window screens in the Middle Eastern dwellings. MADEO, F. and SCHNABEL, M. (eds.), In: *Proceedings of Across: Architectural Research through to Practice: 48th International Conference of the Architectural Science Association*, Genoa, December 2014, the Architectural Science Association & Genova University Press, pp. 479–490.

ALMERBATI, N., FORD, P., TAKI, A., DEAN, L. (2015) Beyond Romantic Mashrabiya: the Production of a Personalized and Efficient window screen in Middle East Dwellings. *In: 9th International Conference on Design Principles and Practices and the Design Principles and Practices knowledge community,* March 2015, Chicago: Common Grounds.

ALMERBATI, N., HEADLEY, D. (2016) Heritage conservation in the new digital era: The benefits of 3D printing architecture screens in sustaining architecture and identity. *In: Proceedings of Sustainable Heritage: local experience global vision, the fourth international architectural conservation conference, Dubai, February 2016, Dubai Municipality*, pp. 1-15.

ALMURAHHEM, F. M. (2011) The Nineteenth Century Western Travelers' Conception of the Harim: Restoring the Cultural Complexity of the Hijab in Architecture*, Islamic architecture* 1 (4), pp. 167-180.

ALMURAHHEM, F. (2008) *Behind the Roshan: Visualising the Roshan as an architectural experience in traditional domestic interiors*. Published thesis (PhD.), University of Brighton.

ALMURAHHEM, F. (1996) *Roshan And Shubak Windows And Their Effect On The Interior Design Of Traditional Houses In Mekka In Early 14th AH (Alroshan wa alshubak wa atharuhoma ala altsmeem aldakli fe biot Mekka Altaqlidiya fe awael alqarn alrabee aashar alhejri)*, Unpublished thesis (MA.), Umm Alqura University.

ALNASER N. (2009) Utilisation of Solar and Wind Energy in Buildings in the Kingdom of Bahrain: A Step towards Sustainable Building Construction. Unpublished thesis (PhD.), University of Reading.

ALNASER, W. and ALNASER, N. (2011) The status of renewable energy in the GCC countries. *Renewable and Sustainable Energy Reviews*, 15(6), pp. 3074-3098.

AL-SHAREEF, F. (1996) Natural light control in Hadjazi architecture: an investigation of the Rowshan performance by computer simulation. Unpublished thesis (PhD.), Liverpool University.

AL-SHAREEF, F., OLDHAM, D. and CARTER, D. (2001) A computer model for predicting the daylight performance of complex parallel shading systems. *Building and Environment*, 36(5), pp. 605-618.

AMEEN, F. (1983) A study about the Reality of Bahraini Family in Arabic (Derasa Hawla Waqee Alosra Albahrainia), Bahrain Sociology society.

ANDERSON, J. and TANG, M. (2011) Form Follows Parameters: Parametric Modelling for Fabrication and Manufacturing Processes *in 16th International Conference on Computer-Aided Architectural Design Research in Asia (CAADRIA)*, pp. 91-100.

ANI, R. (1994) *In the Shadows of Segregation: Women's Identity in the Modern Iraqi House*. Unpublished thesis (MSc.), Massachusetts Institute of Technology.

BABAEI, M., SOLTANZADEH, H. and YAHYA, S. (2012) A study of the lighting behaviour of Moshabak in Kashan's houses with emphasis on the notion of transparency. *Architectural Science Review*, pp. 1-16.

BAETENS, R., JELLE, B. and GUSTAVSEN, A. (2010) Properties, requirements and possibilities of smart windows for dynamic daylight and solar energy control in buildings: A state-of-the-art review. *Solar Energy Materials and Solar Cells*, 94(2), pp. 87-105.

BAHRAIN.COM (2015) History and economy. [Online] Bahrain. Available from: http://www.bahrain.com/en/About-Bahrain/Pages/History [Accessed 11/4/2015].

BAHRAINPORT.COM (2015) A long history of Iviation. [Online] Bahrain Airport Company, Available from http://www.bahrainairport.com/ar/about-us/our-history/198-bia-timeline.html, [Accessed 21/4/2015].

BECKETT, R. and BABU, S. (2014) To the Micron: A New Architecture Through High-Resolution Multi-Scalar Design and Manufacturing. *Architectural Design*, 84(1), pp. 112-115.

BEESLEY, P. and SEEBOHM, T. (2000). Digital Tectonic Design. In Promise and Reality: State of the art versus state of practice in computing for the design and planning process. *In: Proceedings of the 18th eCAADe Conference*, Weimar, Germany, 22-24 June 2000, pp. 287–290.

BENEDETTI, C., BARATIERI, M., LEONE, G., MIMMO, T. and PAGLIALONGA, G. (2010) Wood technology for passive cooling. In: *Proceedings of the 11th World Conference on Timber Engineering 2010*, WCTE 2010, June 20-24 2010, Trees and Timber Institute, pp. 2571-2578.

BEN-HAMOUCHE, M. (2013) The corners law: Leftover spaces versus sustainability in Arab Gulf cities the case of Bahrain. *Urban Design International*, 18(2), pp. 114-130.

BEN-HAMOUCHE, M. (2004) The changing morphology of the gulf cities in the age of globalisation: the case of Bahrain. *Habitat International*, 28(4), pp. 521-540.

BENNETT, J. (2012) Looking Behind the Green Facade. *Policy*, 28(3), pp. 30-33.

BERGER, R., (2013). Additive manufacturing: a game changer for the manufacturing industry. *Roland Berger Strategy Consultants GmbH, Munich.*

BERNARD, H.R. (2011) Research Methods in Anthropology, 5th edition, AltaMira Press.

BERMAN, B. (2012) 3-D printing: The new industrial revolution. *Business horizons, 55*(2), pp. 155-162.

BIEM, A. and JENSEN, K.V. (2007) Forming Core Elements for Strategic Design Management: How to Define and Direct Architectural in an Industrialized Context *in Architectural Engineering and Design Management*, Vol 3, Issue 1, p29-38.

BIGGS, M. A. R. (2002). The Rôle of the Artefact in Art and Design Research. *International Journal of Design Sciences and Technology*, 10 (2), 19-24.

BLAXTER,L. ,HUGHES,C. and TIGHT, M. (2006) *How to Research*. Open University Press.

BOHLER, W. and MARBS, A. (2004) 3D scanning and photogrammetry for heritage recording: A comparison, *Proceedings of the 12th International Conference on Geoinformatics*, Citeseer, pp. 291–298.

BOUGDAH, H. and SHARPLES, S. (2009) *Environment, technology and sustainability*. Taylor & Francis.

BOVEA, M.D. and VIDAL, R. (2004) Increasing product value by integrating environmental impact, costs and customer valuation. Resources, Conservation and Recycling, 41(2), pp. 133-145.

BOZTEPE, S. (2003) The Notion of Value and Design, *in Journal of the Asian Design International Conference*. Tsukuba: Institute of Art and Design, University of Tsukuba.

BRIGGS, M. (1974) *Muhammadan architecture in Egypt and Palestine*. New York: Da Capo Press.

BROOKE, E. (2013) Why 3D printing will work in fashion. TechCrunch, July 20. Available from: http://techcrunch.com/2013/07/20/why-3d-printing-will-work-in-fashion/ [Accessed 11/5/2015].

BRYMAN, A. (2012) 4th ed. *Social Research Methods*. Oxford University Press.

CAMPBELL, R.I. et al. (2003) The Potential for the Bespoke Industrial Designer. *The Design Journal*, 6(3), pp.24–34. Available at: http://www.tandfonline.com/doi/full/10.2752/146069203789355273 [Accessed 30/5/2016].

CAMPBELL, RI., BOURELL, D., GIBSON, I. (2012) Additive manufacturing: rapid prototyping comes of age, Rapid Prototyping Journal, 18(4), pp.255-258.

CAMPBELL, R.I., JEE, H. & KIM, Y.S. (2013) Adding product value through additive manufacturing. In U. Lindemann et al., eds. *ICED 13: 19th International Conference on Engineering Design*. The Design Society, pp. 259–268.

CELANI, M., PINHEIRO, A. and GRANJA, A. (2007) Lean thinking and rapid prototyping: towards a shorter distance between the drawing board and the construction site. *Virtual and Rapid Prototyping*, 2007.

CENTRAL INFORMATICS ORGANISATION (2015) *Population*. [Online] Bahrain Data Portal, Available from: http://www.data.gov.bh/en/DataAnalysis/ [Accessed 11/4/2015].

CHARTERIS-BLACK, J. (2004) *Corpus Approaches to Critical Metaphor Analysis*. Basingstoke; New York: Palgrave-MacMillan.

CHOMA, J. (2010) Contested Boundaries: Digital Fabrication + Hand Craft *in SIGRADI: Disrupcion, modelaciony construccion: Dialogos cambiantes*.

COHEN, L., MANION, L. and MORISSON, K. (2011) 7th edition, Research Methods in Education. Routledge.

COLLINS, H. (2010) *Creative Research: The Theory and Practice of Research for the Creative Industries*. AVA Publishing.

CONNER, B.P. et al. (2014) Making sense of 3-D printing: Creating a map of additive manufacturing products and services. *Additive Manufacturing*, 1‑4, October 2014, pp 64-76.

CRESWELL, J. (1994*) Research Design: Qualitative and quantitative Approache*s, London: Sage.

CRESWELL, J. (1998*) Qualitative Inquiry and Research Design: Choosing Among Five Traditions*. London: Sage.

CRILLY, N., MOULTRIE, J. and CLARKSON, P.J. (2004) Seeing things: consumer response to the visual domain in product design. *Design Studies,* 25 (6), pp. *547-577*.

CROLLA, K. and WILLIAMS, N. (2014) Smart Nodes: A System for Variable Structural Frames with 3D Metal-Printed Nodes, ACADIA 14: Design Agency [Proceedings of the 34th Annual Conference of the Association for Computer Aided Design in Architecture (ACADIA). pp. 311-316.

CUREDALE, R. (2013) *Design Research Methods: 150 Ways to Inform Design*. Design Community collage.

CURL, J. S. and WILSON, S. (2015*) Dictionary of Architecture*, Oxford University Press.

DAVIDSSON, H., PERERS, B. and KARLSSON, B. (2012) System Analysis of a Multifunctional PV/T Hybrid Solar Window. *Solar Energy*, 86(3), pp. 903-910.

DAVIS, J. et al. (2012) Smart Manufacturing, Manufacturing Intelligence and Demand-Dynamic Performance. *Computers & Chemical Engineering*, *47*, pp. 145-156.

DAYARATNE, R. (2012) Landscapes of a Nation: Constructing National Identity in the Deserts of Bahrain. *National Identities*, 14(3), pp. 309-327.

DAYARATNE, R. (2008) The traditional and the Hybrid architecture of Bahraini, Isa Town: University of Bahrain.

DAYARATNE, R. and KARAJICA, L. (2007) Assembling Identities and creating architecture intriguing metaphor. In: *Proceedings of the second international conference in the centre of the study of architecture in the Arab region*. Tunisia: CSAAR, p.911-926

DEAN, L. and PEI, E. (2012) Experimental 3D Digital Techniques in Design Practice. In: *Proceedings of the 2nd International Conference on Design Creativity (ICDC2012*) Glasgow, 18th-20th September 2012. United Kingdom.

DELMOJI, S. and FATHY, H. (1986) On the Poetics of Space: Interview with Engineer Hassan Fathy, *Journal of Comparative Poetics*, pp. 62-72.

DIGITAL MEETS HERITAGE, (2015) 3D Printing applied to cultural heritage: Low-cost conservation technique using 3D modeling and printers. (Online) Available from <http://www.digitalmeetsculture.net/article/3d-printing-applied-to-cultural-heritage/>. Accessed 28/8/2015.

DITO, M. (2007) Migration policies and challenges in the Kingdom of Bahrain. In: Proceeding of the *Conference on Migration and Refugee Movements in the Middle East and North Africa*. The American University in Cairo, Egypt.

DRITSAS, S. and YEO, K. (2013). R. Stouffs, P. Janssen, S. Roudavski, B. Tunçer (eds.), Undrawable Architecture: Digital workflows for the conservation of heritage buildings and the discovery of digital tectonic. *In: Proceedings of the 18th International Conference on Computer-Aided Architectural Design Research in Asia (CAADRIA 2013)*, pp. 833–842. The Association for Computer-Aided Architectural Design Research in Asia (CAADRIA), Hong Kong, and Center for Advanced Studies in Architecture (CASA), Department of Architecture-NUS, Singapore.

DUSSAULT, J., GOSSELIN, L. and GALSTIAN, T. (2012) Integration of smart windows into building design for reduction of yearly overall energy consumption and peak loads. *Solar Energy*, 86(11), pp. 3405-3416.

EDB, (2016) Bahrain Development Board: Economic Vision 2030. [Online]. Available from: http://www.bahrainedb.com/. [Accessed on 22/3/2016].

ELAGIB, N. and ADDIN ABDU, A. (1997) Climate variability and aridity in Bahrain. *Journal of Arid Environments,* 36(3), pp. 405-419.

ELDEMERY, I. (2009) Globalization Challenges in Architecture, Journal of Architecture and Planning Research, 26(4), pp. 343-354

ELSAID, I. and Parman, A. (1976) *Geometric concepts in Islamic art*. London: World of Islam Publishing.

ELSHEIK, M. (2011*). Intelligent building skins: Parametric-based algorithm for kinetic facades design and daylighting performance integration*. Unpublished thesis (MSc.), University of Southern California. Available from http://digitallibrary.usc.edu/cdm/compoundobject/collection/p15799coll127/id/15576/rec/8 [Accessed 2/3/2014]

ELSHORBAGY, A. (2010) Traditional Islamic-Arab House: Vocabulary and Syntax, *International Journal of Civil & Environmental Engineering IJCEE-IJENS*, 10(04), pp. 15-20.

FATHY, H. (1973) *Architecture for the poor,* University of Chicago Press.

FATHY, H. (1986) *Natural Energy and Vernacular Architecture*, the United Nation University by the University of Chicago Press.

FRATELLO, R.S. (2015) Cool Brick [Online] Available from: http://www.emergingobjects.com/projects/cool-brick/ [Accessed 5/6/2015].

FATHY, H. and GULMED, S. (1986) On the Poetics of Space Interview with Engineer Hassan Fathy/. *Alif: Journal of Comparative Poetics*, pp. 62-72.

FEENY, J. (1974) *The magic of Mashrabiyas*, Saudi Aramco World, pp.32-36.

FICARELLI, L. (2008) Passive Cooling in Traditional Construction: Case of Domestic Architecture in Egypt.

FICARELLI, L. (2009) The Domestic Architecture in Egypt between Past and Present: The Passive Cooling in Traditional Construction. *In: Proceedings of the Third International Congress on Construction History*. Cottbus: May 2009.

FISHER, T. (2014) Architecture and the 3rd Industrial Revolution. *Architect,* 103(1), pp. 100-103.

FORD, P. and DEAN, L. (2013) Additive Manufacturing in Product Design education: Out with the old in and in with the new? In: *Proceedings of the 15th International Conference on Engineering and Product Design Education: Design Education - Growing Our Future*, EPDE, 2013, pp. 611-616.

FUCCARO, N. (2001) Visions of the city: Urban studies on the Gulf. *Middle East Studies Association Bulletin*, pp.175-187.

GALLO, C. (1996) Passive cooling as design methodology: some examples from the past to the present. *Renewable Energy*, 8(14), pp. 309-314.

GALLO, C. (1998) The Utilization Of Microclimate Elements. *Renewable and Sustainable Energy Reviews*, 2(12), pp. 89-114.

GHIASVAND, J. et al. (2008) Adaptive re-use of Islamic and Iranian architecture's elements. In: *Proceedings of the International Conference on culture Heritage and Tourism, Crete Island, July 2008,* pp.19-24.

GRIER, K.C. (1996) Culture Made Material. *American Literary History,* 8(3), pp. 552-565.

GUARDIAN (2011) World's first zero-carbon city: Masdar in pictures. Available from: http://www.theguardian.com/environment/gallery/2011/apr/26/masdar-eco-city-abu-dhabi. [Accessed 30/5/2016].

GULFINSIDER, (2015) Bahrain Photo gallery. [Online], Available from: https://www.facebook.com/GulfInsider/photos/[Accessed 20/4/2015].

GUNGOR, A. and GUPTA, S.M., (1999) Issues in environmentally conscious manufacturing and product recovery: a survey. *Computers & Industrial Engineering*, *36*(4), pp.811-853.

HASSAN, M. et al. (2007) Investigation Of Effects Of Window Combinations On Ventilation Characteristics For Thermal Comfort In Buildings. *Desalination*, 209(1-3), pp. 251-260.

HAKIM, B. and AHMED, Z. (2006) Rules for the Built Environment in 19th Century Northern Nigeria. *Journal of Architecture and Planning Research*, 23(1), pp.1- 26.

HAGUE, R. (2006) Unlocking the design potential of rapid manufacturing. *Rapid manufacturing: an industrial revolution for the digital age*. West Sussex: John Wiley and Sons.

HAMPTON, O. (2007) Universes in Universe: Nafas Art Magazine, Samta Benyahia: Architecture of the Veil. [Online] Available from: http://universes-in-universe.org/eng/nafas/articles/2007/samta_benyahia [Accessed 10/ 5/2013].

HART, C. (1998) *Doing a literature review: releasing the social science research imagination*, London: Sage Publication.

HAUTE-ELAN, (2015) The evolution of the Abaya. [Online] Available from: http://www.haute-elan.com/blogs/special-feature/23053953-the-evolution-of-the-abaya. [Accessed 10/10/2015].

HEADLEY, D., ALMERBATI, N., FORD, P., TAKI, A. (2015) From research to practice: exploring 3D printing in production of architectural Mashrabiya, R.H. Crawford and A. Stephan (eds.), In: *Proceedings of Living and Learning: Research for a Better Built Environment*: 49th International Conference of the Architectural Science Association 2015, The Architectural Science Association and The University of Melbourne, pp.1009–1017.

HEATH, J. (2008) *Veil: Women Writers on Its History, Lore, and Politics*. [online book] University of California Press, Berkeley, CA, USA. Available from: ProQuest ebrary. [Accessed17/5/2015].

HEATHCOTE, E. (2010) Blurred boundaries. *Financial Times, 7*.

HENSEL, M. (2008) Performance-Orientated Design Precursors and Potentials. *Architectural design*, *78*(2), pp. 48-53.

HERBIG, U., JGER-KLEIN, C., MAYER, I., MORTADA, H. and STYHLER-AYDIN, G. (2013). Trabasa-traditional architecture recorded by means of building archaeology in Saudi Arabia: Workshop in Jeddah. *ISPRS-International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, 1(2), pp. 331–336.

HOLBROOK, M. (l999) *Consumer Value: A Framework for Analysis and Research*, New York: Routledge.

HOLBROOK, S. (2013) The promise of 3D printing: Printing the world on your descktop. [Online]. *Make*. Pp.8-. available from:
http://www.timelab.org/sites/all/files/MAKE_Ultimate_Guide_to_3D_Printing.pdf. (Accessed on 1/4/2015).

HOPKINS, T. (2014) *An Architecture of Thresholds: Environmental Exuberance,* Master Thesis, University College London.

HOPKINSON, N. (2006) *Rapid manufacturing: an industrial revolution for the digital age*. West Sussex: John Wiley.

HUI, C. (2005) *Vernacular precedent adaptation in design in terms of sustainability: comparative study on Le Corbusier and Hassan Fathy*. Unpublished thesis (MA.), National University of Singapore.

HVIDT, M. (2013) *Economic diversification in GCC countries: past record and future trends.* Kuwait Programme on Development, Governance and Globalisation in the Gulf States, 27. London School of Economics and Political Science, London, UK.

INVESTOPEDIA (2016) What is 'accretive'?, [Online] Available from http://www.investopedia.com/terms/a/accretive.asp, [Accessed in 6/4/2016].

KALLIOPI, F. (2016) Sustainable Heritage Definition. [Email]. Received 6/4/2016.

KARAMATA, B. and ANDERSEN, M. (2014) Concept, Design and Performance of a Shape Variable Mashrabiya as a Shading and Daylighting System for Arid Climates, *30th PLEA Conference-Sustainable Habitat For Developing Societies* 2014, CEPT University Ahmedabad, pp. 344-351.

KARANOUH, A.M. (2009) Algorithmic Design and Intelligent Skins. Unpublished thesis (MSc.). Bath University.

KARANOUH, A.M. (2013) Albahar tower concept and development. [Email] Received on 1/4/2013.

KAROLAK, M. (2010) Religion in a Political Context: The Case of the Kingdom of Bahrain. *Journal of Global Studies*, 4(1), pp.4-25.

KAPLAN, C. (2002) *Computer graphics and geometric ornamental design*. Unpublished thesis (PhD.), University of Washington.

KAPLAN, C. (2009) Semiregular patterns on surfaces. *In: Proceedings of the 7th International Symposium on Non-Photorealistic Animation and Rendering* (NPAR '09), Stephen N. Spencer (Ed.). New York: ACM, pp. 35-39.

KAZEROONI, F. (2002) *Gulf Islamic Architecture*, Manama: Oriental Press.

KEELEY, M. (2013) The new industrial revolution, *Gulf industries*, May 2013, pp. 55-58.

KENZARI, B. & ELSHESHTAWY, Y. (2003) The Ambiguous Veil: On Transparency, the Mashrabiy'ya, and Architecture', *Journal Of Architectural Education*, 56(4), pp. 17-25.

KEOLEIAN, G.A. and MENEREY, D., (1994) Sustainable development by design: review of life cycle design and related approaches. *Air & Waste*, 44(5), pp.645-668.

KHALIFA, N. (2009) *Almuharaq bayna althabat wa altaqieer (Muharraq between remain and change: a field study of social change) (in Arabic),* Manama: Alraja Printing press

KHALIFA, N. (2012) *Alriffa altatawer altareky wa taatherat alnomow alhadary (Riffa the historical development and the effect of social development) (in Arabic)*, Manama: Alraja Printing press

KHANGHAHI, T. and ABDOLMALEKI, P. (2011) An Overview of the Iranian Vernacular Architecture with Particular Reference to the Air Traps. *International Journal of Academic Research*, 3(1), pp. 793-799.

KHONDKER, H.H., (2011) Role of the new media in the Arab Spring.Globalizations, 8(5), pp.675-679.

KILLAM, L. (2013) *Research terminology simplified: Paradigms, axiology, ontology, epistemology and methodology*. Sudbury: ON.

KIM, G. et al. (2012) Comparative advantage of an exterior shading device in thermal performance for residential buildings. *Energy and Buildings*, *46*(0), pp. 105-111.

KIM, S.J., KARA, S. and KAYIS, B. (2014) Economic and environmental assessment of product life cycle design: volume and technology perspective. *Journal of Cleaner Production, 75*(0), pp. 75-85.

KINNINMONT, J. (2015) Analysis: Bahrain economic challenges. [Online] available from: http://www.middleeasteye.net/news/analysis-bahrains-economic-challenges-1463229931 [Accessed 21/4/2015]

KO, K. and LIOTTA, J. (2011). Decoding Culture Parametrically: Digital Tea House Case Studies. International Journal of architectural computing, 4(9), pp.325-329.

KOLAREVIC, B. (ed.), (2003). *Architecture in the Digital Age: Design and Manufacturing*, Routledge.

KOTEY, N. et al. (2009) Solar Gain through Windows with Shading Devices: Simulation versus Measurement. *ASHRAE Transactions*, 115(2), pp. 18-30.

KOTNIC, T. (2005) The Mirrored Public: Architecture and Gender Relationship in Yemen. *Space and Culture*, 8, pp. 472-483.

KNOX, K. (2012) *culture to Catwalk: How world culture influence fashion*, Susan James.

KREJCIE, R. and MORGAN, D. (1970) *Determining sample size for research activities, educational and psychological measurement,* 30, pp. 607-610.

KRUTH, J. LEU, M. and NAKAGAWA, T. (1998) Progress in Additive Manufacturing and Rapid Prototyping. *CIRP Annals - Manufacturing Technology*, *47*(2), pp. 525-540.

KUMAR, M. (2008) The role of product design in value creation, transmission and interpretation: implications for consumer preference. Unpublished thesis (PhD.), University of Mississippi.

LEE, M. (2015) Critical metaphor analysis of citizenship education discourse. *Public Relation Inquiry*, 4(1), pp. 99-123.

LEWCOCK, R. and FREETH, Z. (1978) *Traditional Architecture in Kuwait and the Northern Gulf*. London: Art and Archaeology Research papers.

LEVOY, M., PULLI, K., CURLESS, B., RUSINKIEWICZ, S., KOLLER, D., PEREIRA, L., GINZTON, M., ANDERSON, S., DAVIS, J. and GINSBERG, J., (2000). The digital Michelangelo project: 3D scanning of large statues. *Proceedings of the 27th Annual Conference on Computer Graphics and Interactive Techniques* 2000, ACM Press/Addison-Wesley Publishing Co., pp. 131–144.

LIM, S., BUSWELL, R.A., LE, T.T, AUSTIN, S.A., GIBB, A., THORPE, T.(2012) Development in construction-scale additive manufacturing processes. *Automation in Construction*, 21, pp.262-268.

LIPSON, H. and KURMAN, M. (2013) Fabricated: The New World of 3D Printing. Somerset, NJ, USA: John Wiley & Sons.

LOCKERBIE, J. (2015) Catnaps.org: Gulf architecture, [Online]. Available from http://catnaps.org/islamic/design.html [Accessed 15/3/ 2014].

LOUGHBROUGH UNIVERSITY (2015) Robust Models for Project Meetings [Online] available from http://www.lboro.ac.uk/microsites/enterprise/e2hs/technology/HSS/case-studies/robust-parts.html [Accessed 13/3/2015].

LUECKE, G. and SLAUGHTER, J. (1995) Design, development, and testing of an automated window shade controller. *Journal of Solar Energy Engineering,* 117, pp.326-332.

MAITREYA, V. (1988) Environmental parameters in building design. *Building and Environment*, 23(2), pp. 115-121.

MANDALAKI, M. et al. (2012) Assessment of fixed shading devices with integrated PV for efficient energy use. *Solar Energy*, 86(9), pp. 2561-2575.

MARTIN, B. AND HANINGTON, B. (2010) *Universal Methods of Design: a 100 ways to research complex problems, develop innovative design ideas and design effective solutions*. Beverly: Rockport publishers.

MAYER, I. and STYHLER-AYDIN, G., (2012) 3D laser measurement as part of an integrative building survey for the recording of built heritage. In: *Proceedings of the International Conference on Cultural Heritage and New Technologies*. Vienna, Italy.

MAXWELL, J. (2005) *Qualitative Research Design: An Interactive Approach* (2nd Ed.). Thousand Oaks, CA: Sage.

MEINHOLD, B. (2010) 3D Printed Sand Pods Create Cooling Microclimates: Inhabitat - Sustainable Design Innovation, Eco Architecture, Green Building. INHABITAT | DESIGN FOR A BETTER WORLD!. Available from: http://inhabitat.com/3d-printed-sand-pods-create-cooling-microclimates/ [Accessed 12/4/2014].

MINSTRY OF HOUSING.GOV (2015) Mission and Vision. [Online] Available from: http://housing.gov.bh/en/AboutUs/Pages/MissionandVision.aspx [Accessed 1/6/2015].

MINISTRY OF INDUSTRY AND COMMERCE.GOV (2015) Bahrain Economic Vision. [Online] Available from: http://www.moic.gov.bh/ [Accessed 18/4/2015].

MITAL, A., DESAI, A. and SUBRAMANIAN, A., (2007) Product Development: A Structured Approach to Design and Manufacture. Burlington, MA, USA: Butterworth-Heinemann.

MITCHAM, C. (2005) Thinking Re-Vernacular Building. *Design Issues*, 21(1), pp. 32-40.

MOIC, (2014). The Bahrain Ministry of Industry and Commerce annual report. [Online]. Available online from: http://www.moic.gov.bh/Ar/Main/AnnualReport/Documents. Accessed 20/3/2016.

MODEEN, T. (2005) CADCAMing: The use of rapid prototyping for the conceptualization and fabrication of architecture. *Automation in Construction*, 14(2), pp. 215-224.

MORADI, A. and AKTARKAVAN, M. (2008) Sustainable Architecture in the Hot, Arid and Sunny Regions of Iran, *International Journal of Engineering Science*, 19 (6), pp. 21-29.

MORTADA, H. (2014) Architecture and Urban Distinction of Historic Jeddah. [Online] power point presentation. Available from: http://www.slideshare.net/HishamMort/historic-jeddah-presentation-belin-sept-2014?qid=d3e9a534-7787-4e5b-b637-2983eb063bc4&v=default&b=&from_search=1 [Accessed 13/4/2015].

MORTADA, H. and JOSHI, K.N. (2013) Laser scanning as an advanced mapping tool in the assessment and documentation of traditional architecture. *Indian Cartographer*, XXXIII, pp. 528–532.

MORTADA, H., (2011) *Traditional Islamic principles of built environment*. RoutledgeCurzon, New York.

MOUSSAVI, F. (2008) The Function of Ornament i*n Kubo, M. (ed) The Function of Ornament*, Harvard Graduate School of Design.

MOUSTAFA, N. (2008) *Divine Inspiration: seven principles of Islamic architecture*, IAMM Publication.

NAGY, D. (2014) Growing Details *in AD Future Details of Architecture ed. Mark Garcia*. Wiley, 4.2014. pp. 98-103.

NATIONAL ACADEMY OF ENGINEERING (2012) *Frontiers of Engineering 2011: Reports on Leading-Edge Engineering from the 2011 Symposium*. Washington, DC, USA: National Academies Press.

NET INDUSTRIES (2009) Building Design/Architecture Building Design Industrial Revolution New Materials, [online] source. Available from http://science.jrank.org/pages/1073/Building-Design-Architecture-Industrial-Revolution-new-materials.html [Accessed 13/3/2015].

NIEDDERER, K. AND ROWORTH-STOKES, S. (2007) The Role and Use of Creative Practice in Research and its Contribution to Knowledge*, IASDR07*. International Association of societies of Design Research. Hong Kong, China, November 2007: Hong Kong Poly technic University.

NIKOOFARD, S., UGURSAL, V.I. and BEAUSOLEIL-MORRISON, I. (2011) Effect of external shading on household energy requirement for heating and cooling in Canada. *Energy and Buildings*, 43(7), pp. 1627-1635.

OGANDO, J. (2008) The Art Of 3-D Printing: Design And The Elastic Mind Spotlights The Potential--And Limitations--Of Additive Manufacturing Technologies. *Design News,* 63(6), pp. 10-10.

OTHMAN, Z., AIRD, R. and BUYS, L. (2015) Privacy, modesty, hospitality, and the design of Muslim homes: A literature review. *Frontiers of Architectural Research,* 4(1), pp. 12-23.

OUROUSSOFF, N. (2010) In Arabian Desert, a Sustainable City Rises. *The New York Times*, pp. A1.

OWED, T. (2013) When Less Is More: The Take Way on Milling Vs. 3D Fabrication, Make: ultimate guide to 3D printing, pp. 10-11.

PATIAS, P. (2007) Cultural heritage documentation. In: FRYER, J., MITCHELL, H. and CHANDLER, J. (eds.), *Application of 3D Measurement from Images*. Volume 59. Whittles: Dunbeath, UK, pp. 225–257.

PAVLIDIS, G., KOUTSOUDIS, A., ARNAOUTOGLOU, F., TSIOUKAS, V. and CHAMZAS, C., (2007). Methods for 3D digitization of cultural heritage. *Journal of Cultural Heritage*, 8(1), pp. 93–98.

PERKS, H., COOPER, R. and JONES, C. (2005) Characterizing the Role of Design in New Product Development: An Empirically Derived Taxonomy. *Journal of Product Innovation Management*, 22(2), pp. 111-127.

PILLER, F.T. (2010) Mass Customization: A Strategy for Customer-Centric Enterprises - A Review of the Strategic Capabilities to Make Mass Customization Work. *SSRN Working Paper Series*. Available at: http://search.proquest.com/docview/1095320609?accountid=10472. [Accessed 30/5/2016].

PITTS, A. (2004) *Planning and design strategies for sustainability and profit*, Oxford: architecture press. Elsevier.

PONCHE, R., HASCOËT, J.Y., KERBRAT, O. and MOGNOL, P., 2012). A new global approach to design for additive manufacturing: A method to obtain a design that meets specifications while optimizing a given additive manufacturing process is presented in this paper. *Virtual and Physical Prototyping*, *7*(2), pp.93-105.

POSTLER and FERGUSON (2009) Microclimate. Available from: http://www.postlerferguson.com/ [Accessed on 1/5/2013].

POSTLER, M. (2013) Microclimates future. [Email] sent on 16/5/2013 from n.almurbati@gmail.com to info@postlerferguson.com

PUNCHTA, C. and POTTER, J. (2004*) Focus Group Practice*. SAGE.

RABBAT, N. (2012) What is Islamic Architecture anyway? Journal of Art Historiography, 6. pp. 1-15.

RADHI, H. (2008) A systematic methodology for optimising the energy performance of buildings in Bahrain. *Energy and Buildings*, 40(7), pp. 1297-1303.

RADHI, H. (2009) A comparison of the accuracy of building energy analysis in Bahrain using data from different weather periods. *Renewable Energy*, 34(3), pp. 869-875

RADHI, H. (2009) Can envelope codes reduce electricity and CO2 emissions in different type of building in the hot climate of Bahrain, *Energy*, 34, pp. 205-215.

RADHI, H., ELTRAPOLSI, A. and SHARPLES, S. (2009) Will energy regulations in the Gulf States make buildings more comfortable: A scoping study of residential buildings. *Applied Energy*, 86(12), pp. 2531-2539.

RADHI, H. and SHARPLES, S. (2013) Global warming implications of facade parameters: A life cycle assessment of residential buildings in Bahrain. *Environmental Impact Assessment Review*, 38(0), pp. 99-108.

RAEL, R. and FRATELLO, R.S. (2011) Developing Concrete Polymer Building Components for 3D Printing, ACADIA 2011: Integration through Computation [Proceedings of the 31st Annual Conference of the Association for Computer Aided Design in Architecture (ACADIA), pp. 152-157.

RAJA, V., ZHANG, S., GARSIDE, J., RYALL, C. and WIMPENNY, D. (2006) Rapid and cost-effective manufacturing of high-integrity aerospace components. *International Journal of Advanced Manufacturing Technology,* 27(7), pp. 759-773.

RAGETTE, F. (2012) Traditional Domestic Architecture of the Arab Region. Sharjah: American University of Sharjah.

RASHID, M. and ARA, D.R. (2015) Modernity in tradition: Reflections on building design and technology in the Asian vernacular. *Frontiers of Architectural Research,* 4(1), pp. 46-55.

REMONDINO, F. (2011) Heritage recording and 3D modeling with photogrammetry and 3D scanning. *Remote Sensing*, 3(6), pp. 1104–1138.

RHYNA, T., PETRICK, I., STRIUKOVA, M. (2013) 3D printing: the next industrial revolution. *Special issue of international journal of Manufacturing Technology and Management.*

ROAF, S. & CRINCHTON, D. & Nicol, F. (2005) *Adapting buildings and cities for climate change: a 21st century survival guide.* Oxford: Architectural press.

ROBINSON, L. and PARMAN, A. (2010) Research inspired Design: A step by step guide for interior designers. New York: Fairchild Book

ROUSSEAU, P. and MATHEWS, E. (1996) A new integrated design tool for naturally ventilated buildings. *Energy and Buildings*, 23(3), pp. 231-236.

RUFFO, M., TUCK, C. and HAGUE, R. (2006) Cost estimation for rapid manufacturing –laser sintering production for low to medium volumes. *Proceeding of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture,* 220(9), pp. 1417-1427.

SAELENS, D., PARYS, W., ROOFTHOOFT, J. and DE LA TORRE, A.T. (2013) Assessment of approaches for modelling louver shading devices in building energy simulation programs. *Energy and Buildings*, 60(0), pp. 286-297.

SAFARZADEH, H. and BAHADORI, M. (2005) Passive cooling effects of the courtyards. *Building & Environment.* 40, pp. 89-104.

SALOMON, D. (2011) Experimental Cultures: On the 'End' of the Design Thesis and the Rise of the Research Studio. *Journal of Architectural Education*, 65(1), pp. 33-44.

SAMUELS, W. (2011) *Performance and Permeability: An investigation of the Mashrabiya for Use within the Gibson Desert.* Unpublished thesis (MArch.), Victoria University of Wellington.

SAVERY, J.R. and DUFFY, T.M., (1995) Problem-based learning: an instructional model and its constructivist framework. *Educational Technology*, 35 (5), pp. 31-38.

SCARCE, J. (2003) Women's Costume of the Near and Middle East. Routledge Curzon.

SCHIMELPFENIG, E. (2013) Design and the 3D Printing Revolution. *Kitchen & Bath Design News*, 31(10), pp. 20-20.

SEDKY, A. (1999) The Factors Influencing the Change in Cairene Domestic Architecture After the Ottoman Conquest', In: Proceedings of the 11th International Congress of Turkish Art, Utrecht - The Netherlands, August 23-28, No. 38, pp.1-23.

SHARPLES, S. and RADHI, H. (2013) Assessing the technical and economic performance of building integrated photovoltaic and their value to the GCC society. *Renewable Energy*, *55*(0), pp. 150-159.

SHERIF, A., EL-ZAFARANY, A. and ARAFA, R. (2012) External perforated window Solar Screens: The effect of screen depth and perforation ratio on energy performance in extreme desert environments. *Energy and Buildings*, *52*(0), pp. 1-10.

SICK, F. (1998) *Photovoltaics in buildings a design handbook for architects and engineers*. London, James & James

SIDAWI, B. (2012) A Conceptual Analytic Model of the Vocabulary of the Islamic Architectural Heritage, Emirates Journal for Engineering Research, 17 (1), pp. 47-56.

SMITH, P. (2005) *Architecture and climate of change*. Oxford: Architectural Pres

SOAR, R. and ANDREEN, D. (2012) The Role of Additive Manufacturing and Physiomimetic Computational Design for Digital Construction. *Architectural Design*, 82(2), pp. 126-135.

SRIVASTAV, P. (2009) Use of traditional passive strategies to reduce the energy use and carbon emissions in modern dwellings. *Low-Carbon Technologies*, 4(3), pp. 141-149.

STAKE, R. (1995) *The art of case study research*. London: Sage.

STARCK, P. (2014) Interview with Philippe Starck. Available from http://redvisitor.com/people/philippe-starck/ [Accessed on 1/5/2014]

STRAUSS, H. (2013) AM Envelope: The Potential of Additive Manufacturing for Façade Construction. Architecture and the Built Environment, V1.

SULLIVAN, L. (1896) The Tall Office Building Artistically Considered. *Lippincott's Magazine* (March 1896), pp. 403–409.

SUTTON, D. (2007) *Islamic design: a genius for geometry*. Somerset: Wooden Books.

SYRRAKOU, E., PAPAEFTHIMIOU, S. and YIANOULIS, P. (2006) Eco-efficiency evaluation of a smart window prototype. *Science of the Total Environment*, 359(13), pp. 267-282.

THE ECONOMIST, (2012) the Third Industrial Revolution. [Online] available from http://www.economist.com/node/21553017 [Accessed 13/3/2015].

TRADEARABIA.COM (2015) Bahrain to award over $44bn development projects. [Online] available from http://www.tradearabia.com/news/CONS_280495.html [Accessed 31/5/2015].

ULRICH, K. and EPPINGER, S. (2003), 3rd edition, *Product design and development*. Singapore: McGrow Hill.

VAKLINEZHAD, S., MOFIDI, M., MAHDIZADEH. (2013) 'Shanashil' A sustainable element to balance light, view and thermal comfort. *The international journal of environmental sustainability*. 8 (4), pp. 100- 110. Common grounds publishing.

VERYZER, R.W. (1995) The place of product design and aesthetics in consumer research. *Advances in Consumer Research*, 22, pp. 641-645.

VILLÃN, J. (2009) Pathology of light facades. *Journal of Building Appraisal*, *5*(2), pp. 149-159.

WAINWRIGHT, D. (1997) Can Sociological Research Be Qualitative, Critical and Valid, The Qualitative Report, 3 (2). [Online] Available from (http://www.nova.edu/ssss/QR/QR3-2/wain.html) [Accessed 20/06/2015]

WAI-YIN, C. and SHU-YUN, M. (2004) Heritage preservation and sustainability of China's development. *Sustainable development*, 12(1), pp.15-31.

WALLIS, J. and GREIG, J. (2009) Gradutation design education:the case for an accretive model. *International Journal of Art and Design Education*, 28(3), pp.295-303.

WALLY, T. (1993) *Albayan wa Altebyan fe Al Amara wa alomran (Arabic title)*, Tareq Wally.

WALLIMAN, N. (2005) 2nd edition, *your research project: a step by step guide for the first time researcher*. London: Sage Publication.

WEBSTER, P. (2013) Phill Webster design, [Online] Available from http://www.philwebsterdesign.com [Accessed 20/07/2013]

WELLER, C., KLEER, R. and PILLER, F.T. (2015) Economic implications of 3D printing: Market structure models in light of additive manufacturing revisited. *International Journal of Production Economics,*164, pp. 43-56.

WILLIAMS, C. (2008) *Islamic Monuments in Cairo: The Practical Guide* (5th Edition). Available from: ProQuest ebrary. [Accessed 12/4/2015] American University in Cairo Press.

WITTBRODT, B.T., GLOVER, A.G., LAURETO, J., ANZALONE, G.C., OPPLIGER, D., IRWIN, J.L. and PEARCE, J.M. (2013) Life-cycle economic analysis of distributed manufacturing with open-source 3-D printers. *Mechatronics,* 23(6), pp. 713-726.

WOHLERS, T., (2014). Wohlers report: 3D printing and additive manufacturing state of the industry annual worldwide progress report. Wohlers Associates, USA.

WOHLERS, T., (2012). Wohlers report: 3D printing and additive manufacturing state of the industry annual worldwide progress report. Wohlers Associates, USA.

WOHLERS, T., (2010). Wohlers report: 3D printing and additive manufacturing state of the industry annual worldwide progress report. Wohlers Associates, USA.

WOHLERS, T., (2008). Wohlers report: 3D printing and additive manufacturing state of the industry annual worldwide progress report. Wohlers Associates, USA.

WRIGHT, S. (2010). Fixing the Kingdom: Political Evolution and Socio-Economic Challenges in Bahrain. [Online] Available from: http://hdl.handle.net/10822/558295 [Accessed 18/4/2015].

WU, D., GREER, M.J., ROSEN, D.W. and SCHAEFER, D., (2013). Cloud manufacturing: Strategic vision and state-of-the-art. *Journal of Manufacturing Systems,* **32**(4), pp. 564-579.

YARWOOD, J. (1998), *Almuharraq: Architecture, Urbanism and Society in an Historic Arabian Town.* Published thesis (PhD.), University of Sheffield.

YARWOOD, J. (2001) Al Muharraq: architecture of a traditional Arabian town in Bahrain. *Journal of Art and the Islamic world*, 36, pp. 1-81.

YARWOOD, J. (2005) *Almuharraq*, Manama: Miracle Publishing.

YARWOOD, J. (2011) *Urban Planning in the Middle East: Case Studies*. Cambridge Scholars Publishing.

YASSIN, A. and UTABARTA (2012) Architecture in the Islamic civilization: Muslim building or Muslim Architecture*, Islamic architecture*, 2(2), pp. 52-60.

YHBM.COM. (2015) Winsun Decoration Design Engineering Co. Concrete 3D printing homes technology [Online]. Available from: http://www.yhbm.com/index.php?m=content&c=index&a=lists&catid=67. [Accessed 18/4/2015].

ZORAN, A. (2013) Hybrid Basketry: Interweaving Digital Practice within Contemporary Craft. *Leonardo,* 46(4), pp. 324-331.

ZORAN, A. and BUECHLEY, L. (2013) Hybrid Reassemblage: An Exploration of Craft, Digital Fabrication and Artifact Uniqueness. *Leonardo,* 46(1), pp. 5-10.

3DERS.ORG, (2015) 3D printer and 3D printing news: Price compare-3Dprinters. Available from: http://www.3ders.org/pricecompare/3dprinters/details.aspx?ID=389 [Accessed in 2/5/2015].

APPENDIX A: PUBLICATIONS BY THE AUTHOR CITATIONS AND ABSTRACTS

Peer reviewed conference papers published in conference proceedings:

ALMERBATI, N., FORD, P., TAKI, A., DEAN, L. (2014) From Vernacular to personalised and sustainable: The value of additively manufactured window screens in the Middle Eastern dwellings. MADEO, F. and SCHNABEL, M. (eds.), In: *Proceedings of Across: Architectural Research through to Practice: 48th International Conference of the Architectural Science Association*, Genoa, December 2014, the Architectural Science Association and Genova University Press, pp. 479–490.

HEADLEY, D., ALMERBATI, N., FORD, P., TAKI, A. (2015) From research to practice: exploring 3D printing in production of architectural Mashrabiya, R.H. Crawford and A. Stephan (eds.), In: *Proceedings* of Living and Learning: Research for a Better Built Environment: 49th International Conference of the Architectural Science Association 2015, The Architectural Science Association and The University of Melbourne, pp.1009–1017.

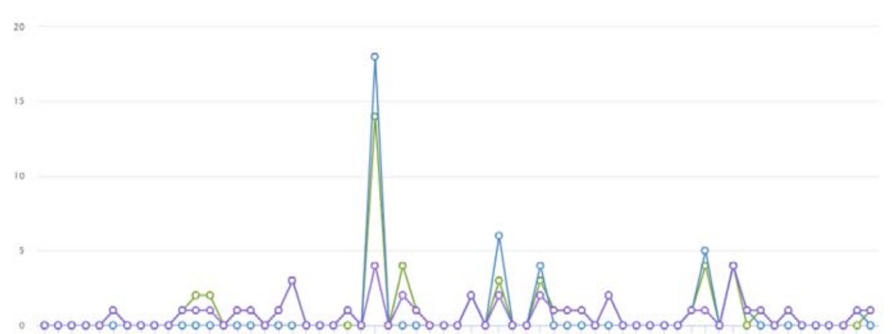
ALMERBATI, N., HEADLEY, D., (2016) Heritage conservation in the new digital era: The benefits of 3D printing architecture screens in sustaining architecture and identity. *In: Proceedings of Sustainable Heritage: local experience global vision, the fourth international architectural conservation conference, Dubai, February 2016, Dubai Municipality*.

Conference presentation:

ALMERBATI, N., FORD, P., TAKI, A., DEAN, L. (2015). Beyond romantic Mashrabiya: the production of a personalized and efficient window screen in Middle East dwellings. *In: 9th International Conference on Design Principles and Practices and the Design Principles and Practices knowledge community,* March 2015, Chicago: Common Grounds.

Journal article:

ALMERBATI, N., HEADLEY, D., FORD, P., TAKI, A., (2016) From manual to hybrid, parametric Mashrabiya: digital workflow for the re-envisioning and conservation of Eastern architectural screens and the engagement of digital tectonics. *The International Journal of Architectonics, Spatial and Environmental Design*. **10**(2). Available online March 31, 2016, from the Design principles and practices.com. pp. 29-39.



Researcher's conference paper interaction and analytical view. Source: Author's academia webpage, March 2016.

F. Madeo and M. A. Schnabel (eds.), *Across: Architectural Research through to Practice: 48th International Conference of the Architectural Science Association 2014*, pp. 479–490. © 2014, The Architectural Science Association & Genova University Press.

FROM VERNACULAR TO PERSONALISED AND SUS- TAINABLE

The value of additively manufactured window screens in Middle Eastern dwellings

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Abstract. The social and environmental role of closed oriental balconies (Mashrabiyas) remains a significant vernacular aspect of Middle Eastern architecture. However, changes in architectural style, social needs, and the high manufacturing cost of Mashrabiya materials and techniques, Bahraini houses lost their very distinctive window veils. The research aims to validate a new Mashrabiya product for 21st century Bahraini houses using new manufacturing technologies. Additive Manufacturing (AM) is now at the heart of evolutionary technologies. Contextual information drawn from relevant theory, ethnography and practice is used to form a methodological framework for the new AM Mashrabiya. Additionally, interviews with architects, manufacturers and residents are the methods used to define a new AM Mashrabiya prototype that is then functionally and economically compared to other manufacturing techniques. Prototypes of new AM screens are developed. The main results set boundaries for the viability of AM to produce Mashrabiya and promote a sustainable way of reviving their use within Middle Eastern dwellings.

Keywords. Mashrabiya, additive manufacturing, innovative construction, personalised products.

Introduction

It is possible to use the traditional (vernacular) architectural elements of the Middle East for problem-solving design solutions in present-day architecture. The potential for achieving these solutions lies in the effective

R.H. Crawford and A. Stephan (eds.), *Living and Learning: Research for a Better Built Environment: 49th International Conference of the Architectural Science Association 2015,* pp.1009–1017. ©2015, The Architectural Science Association and The University of Melbourne.

From research to practice: exploring 3D printing in production of architectural Mashrabiya

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Abstract: Digital fabrication has suggested the supplanting of labour via robotics since it affords substantial increases in speed and accuracy in the development of architectural components. This potentiality might offer solutions for architectures on the verge of extinction due to vanishing skilled labour. This research investigates the possibilities of using new manufacturing techniques to replace the historic artisans with digital master craftsmen, specifically re-developing the Mashrabiya. The work looks at several case studies in architecture and 3D printing; bridging the gap between historically relevant climactic design strategies and digital or parametric design and fabrication. This paper concludes with a summary of a parametrically developed Mashrabiya screen system developed by the authors that is programmable based on core criteria found in the archetype and is currently being explored for product development. The work contributes to the developing body of knowledge surrounding the applications and implications of technologies that enable mass customization.

Keywords: Mashrabiya; architecture; 3D printing; façade; parametric design.

1. Introduction

"Architecture needs mechanisms that allow it to become connected to culture. It achieves this by continually capturing the forces that shape society as material to work with it. Architecture's materiality is therefore a composite one, made up of visible as well as invisible forces." Moussavi (2008).

Contemporary 3D printing is currently disputing the boundaries of construction and manufacturing which were previously confined within traditional making techniques. As a result, this is generating a gap between digital intentions and physical media (Choma, 2010). Choma (2010) appropriately asked the question: "How do we qualify the necessities of fabrication processes in the current discourse?" Market demands and the changes in social lifestyle have demanded innovation of traditional products to suit today's needs. In the Middle East, since the early ages of the Islamic religion, the harsh environment

Heritage conservation in the new digital era: The benefits of 3D printing architecture screens in sustaining architecture and identity

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ABSTRACT

This paper explores the assessment and implementation of cutting edge technologies in the preservation of architectural heritage archetypes, specifically looking at the Mashrabiya. Culture, architecture and heritage are interwoven and shaped by local and nation history that is embedded in traditional building modes. As resources become constrained and globalization provokes more homogenous landscapes, emerging technologies – specifically parametric modeling, 3D printing and 3D scanning - suggest a vital solution in preserving and sustaining traditional cultural building constructs. Additionally, these technologies can not only be used to understand the complexities of the original design intentions but also suggest dimensions in which the heritage architypes can be evolved.

The research implements both case study and focus group methods to validate the use of 3D printing in reproducing architectural Mashrabiya. Mashrabiya, the lattice wooden screen, is deeply rooted in the heritage and supernal culture of several GCC countries and other Islamic societies. Case studies of several historical preservation projects exploring the implementation of technology for heritage preservation are discussed. Subsequently, a comparative analysis is used to examine focus groups and market research data gathered to interrogate the benefits of new 3D printing technology for a parametric Mashrabiya model developed by the authors. The model presented revives old Mashrabiya screens maintaining its visual and thermal comfort performance criteria as well as the historical and social value in a contemporary style.

The authors are interested in the implications of new digital craftsmen and fabricators, whose knowledge contributes new understandings of potential Mashrabiya manufacturing methods. The controlling and programming of relevant input data enables the generation of assemblies that not only support functional performance but also inform the cultural heritage trajectory. This research.

From Manual to Hybrid, Parametric Mashrabiya: Digital Workflow for the Re-envisioning and Conservation of Eastern Architectural Screens and the Engagement of Digital Tectonics

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Abstract: This research seeks to bridge the gap between traditional artisans and emerging digital craftsmen generated by the Arts and Crafts movement of the late nineteenth century and the third Industrial Revolution (Krugh 2014; Economist 2012) now underway via material culturalism as outlined by Grier (1996). Mashrabiya, an Eastern patterned screen, represents an architectural construction that is rooted in cultural and functional parameters, but whose craftsmen have become essentially extinct due to industrialization. In looking at the preservation and redesign of this archetype, the digital tectonic (Beesley and Seebohm 2000) becomes a powerful agent in reconciling tradition with contemporary manufacturing via 3D printing. The authors are exploring the cultural foundations of the Mashrabiya in order to understand how these act as measurable parameters in the re-envisioning of the construction. This paper presents the background, relevant work, and the workflow for the first array of 3D-printed Mashrabiya, exploring their viability and re-insertion into architecture.

Keywords: Mashrabiya, Culture, Craft, 3D Printing, Parametric Architecture, Heritage Conservation.

I. Introduction

Material culturalism is defined by Grier (1996) as the study of a subject matter that takes in the 'biosocial environment' from cultural buildings and landscapes. These valuable collections of artifacts reflect the lifestyles, interactions, environments and eras of people's parents. Material culturists believe that the study of objects and artifacts and the circumstances in which they were made reveals unique perspectives and data that have not been well documented. Islamic Architecture is a rich cultural example with its delicate and geometrically advanced artifacts and production methods (Kaplan 2002). Analysis into historic archetypes, specifically Mashrabiya, can significantly influence the current and future design of architecture facade treatments that could comply with the harsh environmental conditions in the Middle East.

John Fenny (1974) poetically describes the silken masks of the Mashrabiya as symbolizing the "legendary mystery of the Orient." Within Eastern cultures, this architectural construction is a three-dimensional, carved wood lattice structure whose primary function is to control visual privacy as well as temperature and lighting in interior spaces (Samuels 2011). The Mashrabiya, as studied by Hassan Fathy (1986), represents an architectural screen that has five functional dimensions that are achieved through parametric variation in the material thickness and member density: controlling the passage of light, controlling the air flow, reducing the temperature of the air current, raising the humidity of the air current, and ensuring the privacy of the inhabitants within the *Haramlak* or *Harim* (women's quarter) in the courtyard houses of Saudi Arabia, Egypt, Turkey and other eastern countries (see Abdelgelil 2006; Almurahhem 2011).

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COMMON GROUND

APPENDIX B: EXHIBITIONS AND PARTICIPATIONS

Visited Exhibitions:

- Water and Energy conservation Forum and exhibition, 17- 19/6/2013, Bahrain.
- TCT Show conference and exhibition, 25/9/2013, Birmingham, UK.
- Façade Design Summit 8-9/9/2014, in Dubai, UAE.
- Engineering Design Show, 22- 23/10/2014, Coventry, UK.
- DEVELOP3D live conference and exhibition, 26/3/2015, Coventry, UK.
- GULF BID Interior design Exhibition, 20/5/2015, Bahrain.
- TCT Show conference and exhibition, 1/10/2015, Birmingham, UK.
- 4th International Architecture Heritage Conservation Conference and exhibition, 14-16/2/2016, Dubai, UAE.
- Shape to Fabrication conference and exhibition, 19-20/4/2016, London, UK.

Workshops outside DMU:

- 3D Printing and CNC capabilities workshop, 20/8/2013, Bahrain.
- Autodesk certified program for 3DS Max Studio, 20/11/2013-20/1/2014, Bahrain.
- Ideas development and options analysis (product development seminar 3), 13/11/2014, by the Dock, Leicester, UK.

Webinars:

- Next generation manufacturing with additive materials, 23/3/2016. Presentation by: Cameron Knapp, R&D engineer for Los Alamos National Laboratory's Metallurgy Group, and Kelsey Carvell is a medical device and technology innovator for Deloitte in Boston, Massachusetts.
- Digital manufacturing- precision, scale, speed, 17/9/2015.
- An Introduction to GTAM - Topology Optimisation for ANSYS Workbench, 1/4/2015.
- 3D printed tool design in 7 steps, 4/2/2015 by Javelin tech.
- NVivo and RefWorks: improving your literature review, by Americas NVivo events, 12/11/2014.

APPENDIX C: RESEARCH METHODS STANDARD OPERATIVE PROCEDURE (SOP)

Survey Protocols

- Defining research aim and objectives of questions
- Writing key question in relation to research themes
- Identify the survey respondents and location
- Conduct the pilot study
- Refine the questions, their order and translation
- Conduct the survey
- Collect the required data
- Analyse the data
- Prepare the semi- structured interviews question and model prototype
- Discuss the results and conclude

Semi- Structured interview protocols

- Defining interview aim and objectives of interview questions
- Writing key question in relation to research themes
- Identify the experts and major manufacturers to be interviewed
- Contact interviewees and arrange for site interviews or online ones.
- Conduct the interview
- Record the required information
- Take picture and samples of related materials, and manufacturing tools
- Transcribe interviews
- Analyse interviews according to research themes and codes
- Discussion of results and findings

Standard Operating procedure (SOP) for interviews – Manufacturers example

Procedure	Enquiry	Response
At the factory reception	- Hello, I am a research student from DMU, UK. - Where is the head of the design and manufacturing section	Refuse or permit
At the woodwork section	- Hello, I am a research student from DMU, UK. - Where is the person in charge about the facade designs?	Refuse or permit
At the manager or designers desk	- Hello, I am a research student from DMU, UK. - I would like to ask you few questions about your factory and design practice if you don't mind, all data will be used for academic proposes and has been ethically approval	Refuse or permit

Standard Operating procedure (SOP) for interviews – Exhibitors and conferences presenters' example

Procedure	Enquiry	Response
At the Exhibition	- Hello, I am a research student from DMU, UK. - I am interested in architectural scale 3D prints. I would like to ask you few questions about your company and manufacturing materials and machines to an	We do small scale We do large scale
At the conference networking time	- Hello, I am a research student from DMU, UK. - I would like to ask you few questions related to architectural façade in the gulf.	Yes No

APPENDIX D: PUBLIC SURVEY'S QUESTIONS AND ANSWERS SAMPLE

#1

COMPLETE

Collector: Web Link (Web Link)
Started: Monday, April 28, 2014 4:45:39 AM
Last Modified: Monday, April 28, 2014 4:47:53 AM
Time Spent: 00:02:14
IP Address: 109.246.78.106

Q1: **In which type of housing do you currently live? ماهو نوع سكنك الحالي؟**	Flat شقة
Q2: **How many rooms does your housing space contain? كم عدد الغرف في سكنك الحالي؟**	1-3
Q3: **What is your housing ownership type? ما هو نوع ملكية المسكن؟**	Owned ملك خاص
Q4: **When choosing your exterior window treatment, what factor matters the most? Please rank all those relevant in order from 1 downwards: ما هي أهم العوامل التي تؤثر في قرار اختيار التغطية المناسبة لنوافذ المسكن الخارجية؟ الرجاء ترتيبها كلها تنازليا باعتبار 1 اهم تلك العوامل :**	
Visual privacy: Window treatment should respect gender and cultural veil not to show the interior of the room during day or night to outsiders. الخصوصية والستر لاحترام حرمة المنزل ليلا و نهارا	1
Aesthetic: The design and appearance of the selected piece within the exterior image. الخواص الجمالية والشكل الخارجي المناسب للشكل الهندسي للمنزل	2
Function: appropriate shading, swinging, safety and maintenance. الخواص الوظيفية كالامان و التظليل والصيانة	5
Environmental efficiency: Material used sustainability, passive cooling and thermal heat transfer. الخواص البيئية كالمواد المستخدمة و القدرة على التهوية	4
Economics: The cost of the product, its construction material and maintenance cost. الخواص الاقتصادية كسعر المنتج و تكلفة التركيب و الصيانة الدورية	3
Q5: **Do you think there is any other non listed factors that can effect window treatment selection? هل هناك أي عوامل اخرى في نظرك قد تؤثر في عملية اختيار تغطية النوافذ ؟ الرجاء اضافتها**	No
Q6: **Which of the following would you prefer for your property? ما هو الخيار الذي تفضله لمسكنك؟**	Personalized window design (Wooden louvers, Iron grills, Karkari, Mashrabiyya, Stained glass) نوافذ مميزة معدة حسب الطلب والذوق الشخصي مثل المخرمات الخشبية و الجبسية او الكركري او المشربيات او الزجاج المعشق او القضبان الحديدية المزخرفة
Q7: **What pattern would you prefer for an exterior window treatment: ما نوع الزخارف التي تفضلها للنوافذ الخارجية؟**	Floral الزخارف الطبيعية
Q8: **How would you categories personalized window design? ؟ كيف تصنف النوافذ المصنعة تبعاً للطلب الشخصي**	Essential value to building cost قيمة أساسية لقيمة البناء
Q9: **How much are you willing to pay for a personalized window treatment? كم يمكن ان تدفع لتغطية نافذة مصممة للطلب الشخصي؟**	500-1000 BHD
Q10: **How much is your monthly income? ما هو مقدار دخلك الشهري؟**	Bellow 500 BHD
Q11: **What is your age group? ما هي فئتك العمرية؟**	Under 25
Q12: **What is your gender? ما هو جنسك؟**	Female
Q13: **What is your Nationality? ما هي جنسيتك؟**	Bahraini
Q14: **What is your religion? ما هي ديانتك؟**	Muslim

APPENDIX E: INTERVIEWS AND FOCUS GROUPS QUESTIONS

1- **Academic (AC) and scholars interview questions:**

Q1. In your opinion, what are the social and cultural drivers that once affected traditional houses in Bahrain?

Q2. What are the current social and cultural drivers that are now affecting current domestic architecture in Bahrain and other GCC countries?

Q3. How about façade treatment and window shading, what factors affect them in your opinion?

Q4. What are the aesthetic and design solutions that dominate Architecture façade of residential houses today, and especially window treatments in your point of view?

Q5: From your knowledge and observation can you prioritize the function of windows in houses around Bahrain? And how are these functions are reflected on selected shading treatment?

Q6: To what extent does the economic factor and cost of material influence façade design in Bahrain and especially window shading selection in houses?

2- **Architects and interior designers (ARD) interview questions:**

Q1. In your opinion, what are the social and cultural drivers that once affected traditional houses in Bahrain?

Q2. What are the current social and cultural drivers that are now affecting current domestic architecture in Bahrain and other GCC countries?

Q3. How about façade treatment and window shading, what factors affect them in your opinion?

Q4. What are the aesthetic and design solutions that dominate Architecture façade of residential houses today, and especially window treatments in your point of view?

Q5: From your knowledge and observation can you prioritize the function of windows in houses around Bahrain? And how are these functions are reflected on selected shading treatment?

Q6: To what extent does the economic factor and cost of material influence façade design in Bahrain and especially window shading selection in houses?

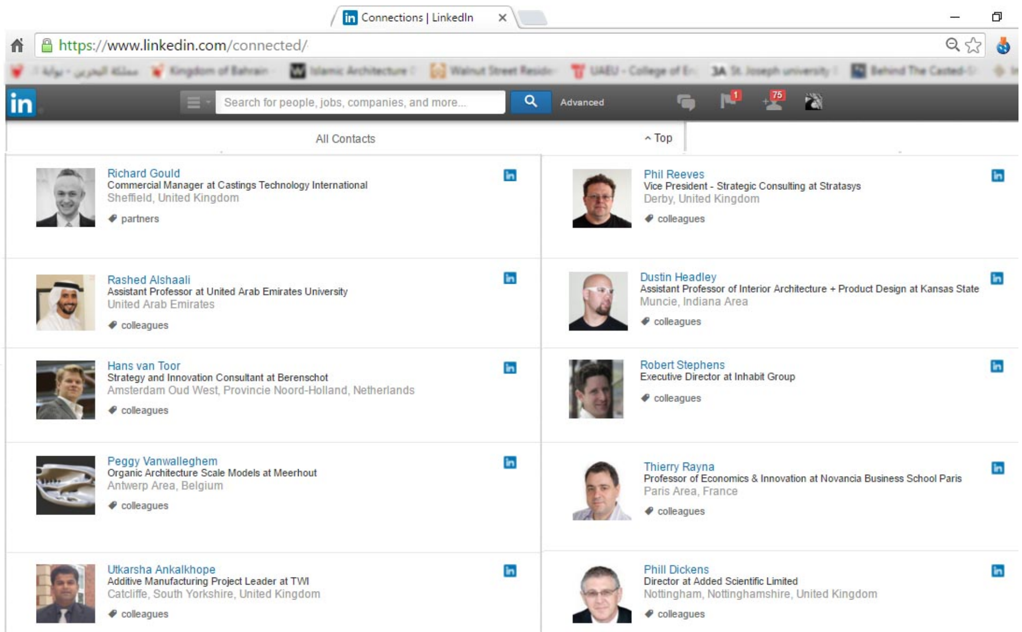
Q7: Do you rely on local manufacturers to produce windows aluminium or wooden or GRC shading devices? If yes can you name the top companies in this filed?

Q8: Is the Bahraini manufacturing market capable of manufacturing any design required by project architects? Please justify your answer.

Q9: In large real estate development project, who determines the facade treatment and the window shading specifications?

Q10: Are there codes and standards in term of the treatment given to windows regulated by the ministry of housing or their Quality assurance division? If yes can you please specify a summary of them?

Q11: From your observation to current architectural style and window treatment what is the most common feature in window design in residential buildings and houses?



Researcher's interviewees partial network. Source: Author's LinkedIn page.

3- Manufacturers (3DS) interview questions:

Q1: How developed would you describe 3DP technologies in the architecture field and what products would it cover now?

Q2: Looking at the rapid growth in the 3dp industry now, how long do you think it will take to produce 3Dp architecture parts that are functional and cost effective?

Q 3: What is the time frame for product development cycle from its infancy to full potential in architecture products; say a screen or a column?

Q 4: What are your predictions for the field of architecture in the time scale you mentioned? And how do you base your prediction?

Q 5: What are the opportunities that 3Dp can offer for architecture productions?

Q 6: What are the obstacles that face Architecture 3Dp development in the world today?

Q 7: What factors in your opinion can fasten the cycle of development for 3Dp in architecture scale?

Q 8: Do you think it is economically viable now to produce a window screen of a meter square using 3DP technologies in a way that challenges CNC screens?

Q 9: Are there business opportunities in 3Dp and architecture that might attract the industry and Architecture firms to invest in this sector? Please justify.

Q 10: How long do you think it will take for 3DP materials and large scale machines like D-shape and Voxeljet VX400 to drop their prices and be affordable for the general public? On what do you build your forecasts in this matter?

Q 11: What is in your opinion is the market scale, size and opportunities for architecture screens?

Q 12: How can you draw your forecasts in this?

4- Possible end users focus groups' discussion questions (FG1-10):

The images attached are rendering of interior and exterior buildings with a 3D Printed Mashrabiya (3DPM) used for privacy and light control.

Warm up question- What style you prefer for your home interior and exterior, including windows design

Theme 1: Aesthetical appearance and customisation preferences

Q1- How would you describe the form of this Mashrabiya?

Q2- Do you like its appearance?

Q3- Do you think you would buy one for your home if it can be customised to your own preferred shape and openings?

Q4- What design feature would you want to adjust or remove in the current design of the screen?

Theme 2: Economical affordability and mind-sets

Q5- A standard screen shading can cost 60 BHD- 1000. If this 3DPM screen would cost 850 BHD, would you buy it for your home as a window shading device?

Q6- Justify your answer?

Q7- How much in your opinion should a screen cost to be reasonably priced?

Q8- If 3DP would allow you more customisation and shape variation options, would you pay for the extra cost?

Q9- What would be the extra percentage you are willing to pay to get the product customised?

```
13/09/2015 5:10:22 pm: You created group "Focus group 9 Eng @8pm"
13/09/2015 6:00:12 pm: Nehal: Dear all thank you for accepting to take part in this focus group about a new mashrabiya des:
A mashrabiya is a lattice window screen used in traditional Bahraini houses to provide ventilation and assure visual priva
13/09/2015 6:00:57 pm: Nehal: e25f30e496753e72444348d3e371083f.jpg <attached>
13/09/2015 6:01:32 pm: Nehal: If you are online, Can you please introduce yourself to the group, name and work title
13/09/2015 6:02:53 pm: SalmamSater Pk: Salman Sater
Air Traffic Controller
13/09/2015 6:02:59 pm: Suhairi 2014: Hi everyone, i am Suhair ,administrator
13/09/2015 6:03:24 pm: Kamal: Hi I'm kamal, 5th year Architecture student
13/09/2015 6:03:39 pm: Nehal: Hi all
13/09/2015 6:04:03 pm: Nehal: I will be asking few questions about a new mashrabiya design using 3d printing technology af
13/09/2015 6:04:23 pm: Suhairi 2014: Yes
13/09/2015 6:04:35 pm: SalmamSater Pk: Approved 👍
13/09/2015 6:05:10 pm: Kamal: Yes
13/09/2015 6:05:34 pm: Lulwa sanad: Hello☆
Lulwa Sanad, an interior designer and a freshman school teacher ☺
13/09/2015 6:05:55 pm: Nehal: Great . Ok let's start by a general question.
What style do you prefer for your home interior and exterior, including windows design?
13/09/2015 6:08:23 pm: You added Fama 2012
13/09/2015 6:08:34 pm: Lulwa sanad: Personally i try not to stick to a certain style. Make it more practical and timeless
And regarding windows, it's nice to have a special idea in windows with considering balance in design to avoid being too m
13/09/2015 6:09:25 pm: Nehal: Thank you Lulwa , how about the others do you prefer modern or classical style ?
13/09/2015 6:09:54 pm: SalmamSater Pk: Definitely modern
13/09/2015 6:09:55 pm: Suhairi 2014: I prefer Classic style
```

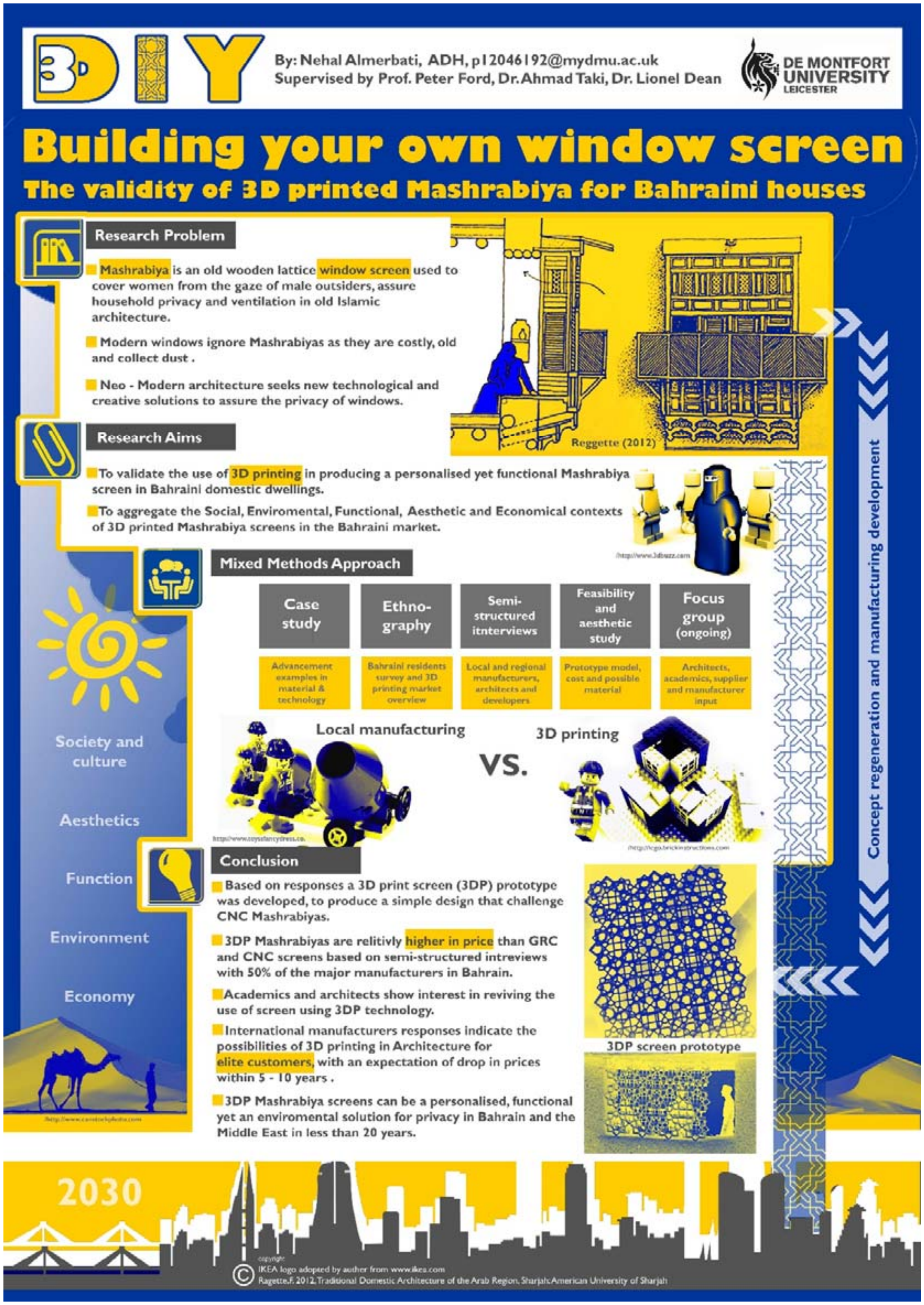
Partial sample text of Focus Group 9 saved online group discussion. Note: images are missing from this part.

APPENDIX F: RESEARCH ACTIVITIES BLOG

- 17- 19/6/2013 attending the Water and Energy conservation Forum, Bahrain.
- 20/8/2013 participating in Bahrain first 3D printing workshop, Bahrain.
- 25/9/2013 TCT show, Birmingham, UK.
- 9/4/2014 wining 3rd place at DMU poster competition, Leicester, UK
- 8-9/9/2014 Attending Façade Design Summit in Dubai, UAE.
- 22- 23/10/2014 attending the Engineering Design show, Coventry, UK.
- 8/11/2014 attending TEDxBrum inspiration DIY theme talks in Birmingham, UK.
- 10-13/12/2014 presenting the Accepted Paper for the 48th International Conference of the Architectural Science Association, Genoa, Italy.
- 3/3/2015 presenting an informal talk to other PhD. Students in the ADH at DMU.
- 12-14/3/2015 presenting the accepted research presentation at the Design Principles and Practices conference in Chicago, USA
- 25/3/2015 winning 4th place at DMU poster competition, Leicester, UK.
- 26/3/2015 attending DEVELOP3D live conference and exhibition, Coventry, UK.
- 24/4/2015 presenting a public talk at the University of the Creative Arts in Canterbury UK.
- 20/5/2015 attending the GULF BID Interior design Exhibition, Bahrain.
- 1/10/2015 attending the TCT show about 3D printing and manufacturing, Birmingham, UK.
- 14-16/2/2016 presenting at the fourth international architecture heritage conservation conference, Dubai, UAE.
- 19-20/4/2016 registered to attend Shape to Fabrication conference in London, UK.

Researcher participations during the PhD course 2013-2016. Source: Author.

Author 3rd prize winner in DMU poster competition 2014.



Author poster wining the 4th place in DMU poster competition 2015.